Journal of Transport & Health 20 (2021) 100968

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: http://www.elsevier.com/locate/jth

# A natural experimental study of new walking and cycling infrastructure across the United Kingdom: The Connect2 programme

Anna Le Gouais [a,*], Jenna R. Panter [a], Andy Cope [b], Jane E. Powell [c], Emma L. Bird [c], James Woodcock [a], David Ogilvie [a], Louise Foley [a], on behalf of the iConnect consortium

[a] MRC Epidemiology Unit & Centre for Diet and Activity Research (CEDAR), School of Clinical Medicine, University of Cambridge, Box 285, Institute of Metabolic Science, Cambridge Biomedical Campus, Cambridge, CB2 0QQ, UK
[b] Sustrans, 2nd Floor, Higham House, Higham Place, Newcastle Upon Tyne, NE1 8AF, UK
[c] Centre for Public Health & Wellbeing, University of the West of England, Bristol (UWE Bristol), Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY, UK

ARTICLE INFO

*Keywords:*
Physical activity
Walking
Cycling
Infrastructure
Context
Evaluation

ABSTRACT

*Introduction:* High quality evaluations of new walking and cycling routes are scarce and understanding contextual mechanisms influencing outcomes is limited. Using different types of data we investigate how context is associated with change in use of new and upgraded walking and cycling infrastructure, and the association between infrastructure use and overall physical activity.

*Methods:* We conducted repeat cross-sectional pre-post analysis of monitoring data from a variety of walking and cycling routes built in 84 locations across the United Kingdom (the Connect2 programme, 2009–2013), using four-day user counts (pre $n = 189,250$; post $n = 319,531$), next-to-pass surveys of route users (pre $n = 15,641$; post $n = 20,253$), and automatic counter data that generated estimates of total annual users. Using multivariable logistic regression, we identified contextual features associated with 50% increase and doubling of pedestrians, cyclists, and subgroups of users. We combined insights from monitoring data with longitudinal cohort data (the iConnect study) from residents living near three Connect2 schemes. Residents were surveyed by post at baseline, one-year ($n = 1853$) and two-year follow-up ($n = 1524$) to investigate associations between use of the new infrastructure and meeting physical activity guidelines.

*Results:* The routes were associated with increased use (median increase in cyclists 52%, pedestrians 38%; $p < 0.001$). Large relative increases were associated with low baseline levels (e.g. odds of doubling cycling were halved for each additional 10,000 annual cyclists at baseline: OR 0.52, 95% CI 0.31, 0.77). Use was associated with meeting physical activity guidelines in both repeat cross-sectional and longitudinal analyses (users vs. non-users after one year, OR 2.07, 95% CI 1.37, 3.21; after two years, OR 2.00, 95% CI 1.37, 2.96).

*Conclusions:* This examination of use, users, benefit-cost ratios, and physical activity associated with new walking and cycling infrastructure across contexts, using multiple types of data, suggests that building walking and cycling infrastructure could improve population health and reduce inequalities.

* Corresponding author.
*E-mail address:* anna.legouais@bristol.ac.uk (A. Le Gouais).

https://doi.org/10.1016/j.jth.2020.100968
Received 3 June 2020; Received in revised form 15 September 2020; Accepted 19 October 2020
Available online 18 December 2020

# 1. Background

Physical inactivity increases risks of non-communicable diseases including cardiovascular disease, stroke, type 2 diabetes, cancers, and mental health conditions, and premature mortality (Warburton and Bredin, 2017). Walking and cycling is advocated as a way to incorporate physical activity into everyday lifestyles (Norwood et al., 2014; Sahlqvist et al., 2012) and the United Kingdom (UK) government has ambitions to double levels of cycling in England between 2013 and 2025 (Department for Transport, 2016). Environmental interventions (those entailing changes to the built environment, such as the construction of new infrastructure) are likely to affect population levels of walking and cycling (Cavill et al., 2019; Goodman et al., 2014). However, evaluating impacts of infrastructure changes can be difficult because research of this nature typically requires natural experimental designs (Craig et al., 2012) with multiple pathways for impact and potentially long timeframes for behaviour change to be seen (Goodman et al., 2014; Ogilvie et al., 2009). Furthermore, infrastructure investment is likely to be provided by transport departments that may not conduct extensive evaluations, despite a stated emphasis on delivering value for money (Department for Transport, 2015). Therefore it is important to understand the utility of monitoring data (e.g. manual counts and surveys of route users) alongside public health research data, which tend to be more scarce (Ogilvie et al., 2005), to demonstrate the outcomes, including economic value, associated with new walking and cycling infrastructure.

We know that elements of physical and social context are important determinants of use of new walking and cycling infrastructure (Götschi et al., 2017; Song et al., 2013) and these contextual issues may be important in influencing decision-makers (Le Gouais et al., 2020). However, there is a lack of published evaluations of use of new and upgraded walking and cycling routes across different contexts and limited understanding of the context-related mechanisms for behaviour change (Panter et al., 2019). Greater understanding about the environmental factors that may influence behaviour change could help explain how features such as bridges, tunnels and transport interchanges impact on facilitating use of new and upgraded walking and cycling routes. This may help to understand heterogeneity of impact of new routes which have been found in other evaluations (Goodman et al., 2013).

User sampling (counts or surveys) conducted as part of monitoring programmes only provide information on users, rather than the general population, but these approaches are cheaper and simpler than longitudinal cohort studies that can compare changes in the behaviour of individuals exposed and unexposed to new infrastructure. In addition, cohort studies tend to have smaller samples than transport monitoring methods which can make the analysis of sub-groups more difficult. Greater understanding of the impact of new infrastructure on sub-groups, including less active groups, would also identify potential impact on inequalities (Aldred, 2019; Macmillan et al., 2018; Panter et al., 2017; Smith et al., 2017), especially since the greatest health gains are expected to arise from increased physical activity by the least physically active (Kelly et al., 2014).

Some studies have suggested that new walking and cycling infrastructure may increase the frequency of journeys for existing users rather than attracting new users (Cavill et al., 2019). Transport sampling methods may not account for displacement of journeys from alternative routes, nor distinguish interventions that encourage existing pedestrians and cyclists to travel further or more frequently from those that encourage new people to walk or cycle, which may produce a greater health gain if they were previously relatively inactive. This may result in an over-estimation of new users and subsequent impact on population health. This can result in associated impacts on calculated benefit-cost ratios (BCRs), which indicate the value for money of a project. It is therefore important to further investigate the association between use of new infrastructure and overall physical activity. Finally, greater availability of cost-benefit analyses of walking and cycling interventions could also be useful to influence investment decisions (Cavill et al., 2019; Smith et al., 2017).

We conducted a repeat cross-sectional, uncontrolled pre-post analysis of data for 84 new and upgraded walking and cycling routes across the UK, built between 2009 and 2013, involving counts and surveys of route users, and estimates of total users (based on a combination of automatic counter data, counts and surveys of users), to answer the following research questions:

1. How do use and estimated BCRs of new walking and cycling infrastructure vary by the nature and local contextual factors of schemes?
2. How does use of new walking and cycling infrastructure by different population sub-groups vary by the nature and local contextual factors of schemes?

Analysis of the survey data was then combined with a longitudinal analysis of repeat postal questionnaire data from a cohort of residents living near three of the routes to answer the research question:

3. What is the association between type of use of new walking and cycling infrastructure and overall physical activity?

The final research question also enables novel investigation of the utility of different methods by combining insights from routine monitoring data alongside public health research data.

# 2. Methods

## 2.1. Intervention

The Connect2 programme involved the creation or upgrading of 84 walking and cycling routes. Each scheme crossed a physical feature such as a river, railway line or major road, for example via new bridges, rehabilitating disused bridges or improving road crossings, plus networks for local traffic-free journeys. These walking and cycling routes were provided across the four countries of the UK, in England (N = 64), Scotland (N = 4), Wales (N = 11) and Northern Ireland (N = 5).

The Connect2 programme was led by the UK walking and cycling charity Sustrans, securing £50 million of investment from the Big Lottery Fund in 2008. Sustrans worked with dozens of stakeholders, including local government, statutory and non-statutory bodies and local community groups, to raise matched funding against the original award and deliver the schemes on the ground. The overall investment in the Connect2 programme was £175 million.

### 2.2. *Measures of use*

We used four datasets to understand use, involving pre and post data from Sustrans' Connect2 programme collected between 2009 and 2013 and the longitudinal iConnect study conducted between 2010 and 2012:

1. Four-day counts of users (71 schemes)
2. Surveys of route users (84 schemes: 78 schemes with pre data, 81 schemes with post data)
3. Estimated total annual scheme users and BCRs (77 schemes)
4. iConnect cohort questionnaires (3 schemes).

The application of each dataset relative to the research questions is described in Table 1. The available data for each Connect2 scheme, alongside contextual features, are described in Table 2.

#### 2.2.1. *Connect2 cross-sectional measures of use and benefit-cost ratios*

The counts of users were recorded manually pre and post construction between 7am and 7pm on 4 day at each scheme. Cross-sectional user surveys were conducted at the same times as the manual counts. Selection was on a next-to-pass basis and informed consent was obtained (see Appendix A for additional details). The user survey asked questions about: frequency of journey on the route; mode of travel; purpose of trip; how long the journey would take; on how many days in the previous week at least 30 min of physical activity had been conducted; and demographic information (see Appendix B).

Total annual scheme users were estimated by Sustrans using a combination of automatic counter data, counts of users, user survey data and trip lengths from the UK Government's National Travel Survey (Department for Transport, 2010). Proxy routes were used for the baseline usage figures for completely new routes. For example, where a new pedestrian and cycling bridge was built, a nearby traffic bridge was used for the baseline measurement.

BCRs were calculated by Sustrans (Sustrans, 2013a) in line with the UK Department for Transport's web-based transport appraisal guidance (WebTag) (Department for Transport, 2013), involving the Health Economic Assessment Tool (HEAT) (World Health Organization, 2011).

Additional details of the methods for estimating total annual scheme users and BCRs are included in Appendix A.

#### 2.2.2. *Cohort survey of residents living in the vicinity of a Connect2 scheme*

The longitudinal iConnect study was conducted with a cohort of adult residents, randomly sampled from the electoral register, living within 5 km of three Connect2 schemes in Cardiff, Kenilworth and Southampton. Postal questionnaires were completed at baseline (before scheme construction) and at one-year and two-year follow-up. Further details of the iConnect methods are published elsewhere (Ogilvie et al., 2012). The iConnect questionnaire asked: whether the local Connect2 route had been used; whether on foot or by bike, and for what purpose; time spent doing physical activity in the previous week; and demographic questions (see Appendix C). Participants who reported that they used the relevant route were classified as users at that time point (i.e. at one-year follow-up and/or two-year follow-up), as pedestrians and/or cyclists, and as users for the particular purposes reported. Previously published iConnect research found that overall physical activity was associated with distance from the new routes (Goodman et al., 2014). This study extends earlier findings to evaluate the association between use of the new routes and meeting guideline levels of physical activity.

### 2.3. *Contextual measures*

#### 2.3.1. *Contextual factors*

Local resident population and presence of a transport interchange within 0.5 mile of the routes were determined using mapping software and 2011 UK census data. Baseline numbers of pedestrians and cyclists were taken from the estimated annual route users before each scheme was constructed (see details in Appendix A). Index of Multiple Deprivation (IMD) ranks were used as a proxy for deprivation, applied at local government level rather than the much smaller Lower Super Output Areas (LSOA) level because many of the schemes were very long and crossed multiple LSOAs in different IMD deciles. Separate deprivation indices were available for rankings in England, Scotland, Wales and Northern Ireland. To allow comparison we calculated UK-adjusted IMD quintiles using Abel et al.'s percentage of the population living in areas in each deprivation quintile by country (Abel et al., 2016).

#### 2.3.2. *Scheme level characteristics*

Scheme designs provided details of route length, cost and whether a bridge or tunnel was present. Cost per mile was not included as

**Table 1**
Research questions, variables and datasets.

| Research question | Exposures | Outcomes | Covariates | Level | Dataset |
|---|---|---|---|---|---|
| **1**: How do use and estimated BCRs of new walking and cycling infrastructure vary by the nature and local contextual factors of schemes? | Contextual factors:<br>• Population living within 0.5 mile<br>• Public transport interchange within 0.5 mile (Yes/No)<br>• Baseline number of users (pedestrians and/or cyclists)<br>• IMD quintile<br>Nature of scheme:<br>• Cost<br>• Length<br>• Bridge/ tunnel present (Yes/No) | **Percentage change in use (pre-post):**<br>At least 50% increase (Yes/No); Double (Yes/No):<br>• Pedestrians<br>• Cyclists<br>**Benefit-cost ratio:**<br>>4 ('very high') | Time from scheme completion to post-monitoring | Scheme level | Total annual scheme users |
| **2**: How does use of new walking and cycling infrastructure by different population sub-groups vary by the nature and local contextual factors of schemes? | Contextual factors:<br>• Population living within 0.5 mile<br>• Public transport interchange within 0.5 mile (Yes/No)<br>• Baseline number of users (pedestrians and/or cyclists)<br>• IMD quintile<br>Nature of scheme:<br>• Cost<br>• Length<br>• Bridge/ tunnel present (Yes/No) | **Percentage change in user sub-groups:**<br>At least 50% increase (Yes/No); Double (Y/N):<br>• Women<br>• Older people<br>• Peak-time users<br>• Women cyclists<br>• Disabled/long term illness<br>• Low SES | Time from scheme completion to post-monitoring | Scheme level | Counts of users; Surveys of users |
| **3**: What is the association between type of use of new walking and cycling infrastructure and overall physical activity? | • Frequency of journey<br>• Time<br>• Mode<br>• Trip purpose | **At least five[a] days with self-reported 30 minutes physical activity in the previous week:** (Yes/No) | Demographics:<br>• Gender<br>• Age<br>• Employment status<br>• Ethnicity<br>• General health<br>• Disabled/ long term illness<br>• Deprivation quintile<br>• Children in household (Yes/No) | Trip level | Surveys of users |
| | • Use (Yes/No)<br>• Mode<br>• Purpose | **At least 150 minutes of self-reported physical activity in the previous week**: (Yes/No) | • Gender<br>• Age<br>• Employment status<br>• General health<br>• Disabled/ long term illness<br>• Deprivation quintile<br>• Children in household (Yes/No)<br>• Baseline physical activity<br>• Scheme | Individual level | iConnect |

IMD = Index of multiple deprivation (UK-adjusted quintiles; see main text).
[a] Four days for users who were running on the route at the time of the survey (see section 2.4.4).

a variable because it was not comparable between schemes which often comprised a mixture of shorter, higher-cost sections (e.g. new bridges) and longer, lower-cost sections (e.g. upgrading an existing path). Instead length and cost were included as these are more relevant to design criteria. They were not strongly correlated (Spearman's rho 0.42) and were therefore treated as independent variables, as were length and population within 0.5 mile (Spearman's rho 0.59).

### 2.4. Outcome measures

#### 2.4.1. Percentage change in use

The percentage changes in use by pedestrians and cyclists were calculated from the total annual scheme users (pre and post). Most schemes reported some increase in cyclists (N = 69 out of 77 schemes (90%)) and pedestrians (N = 63 out of 77 schemes (82%)). Doubling, and increases of at least 50%, in the number of users were chosen as outcomes because of the clarity of message that this was thought to provide to decision-makers in demonstrating successful schemes. The former also relates to the UK government's target of doubling cycling by 2025 in England (Department for Transport, 2016).

#### 2.4.2. Benefit-cost ratio

The UK's Department for Transport defines BCRs of at least 4 as 'very high' value for money (Department for Transport, 2015). This was therefore chosen as an outcome because it was thought likely to be persuasive to decision-makers. It was achieved in 38 schemes (49%).

#### 2.4.3. Percentage change in user sub-groups

Older people, people with long-term illness or disability and people living in the most deprived areas (a proxy for low socio-economic status) were chosen as sub-groups of primary interest because their levels of physical activity tend to be lower (NHS Digital, 2017) and increases in these user groups could lead to greatest health benefits and impact on health inequalities (Kelly et al., 2014; Li et al., 2016; Marmot et al., 2020; Sattelmair et al., 2011; Smith et al., 2016). Women's physical activity is generally lower than men's (Guthold et al., 2018) and there is an increasing realisation of the importance of understanding gender impacts of interventions (Brown and Smith, 2017; Criado Perez, 2019), therefore women were also included as a sub-group. Peak time users were chosen because these may impact on levels of traffic congestion and therefore be of interest to the transport sector. Women cyclists were included as they were under-represented in the UK (Department for Transport, 2016).

Separate outcomes of 50% increase or doubling sub-group users were analysed because these are large increases which may be influential to decision-makers.

Percentage changes of women, older people, peak time users and women cyclists were calculated from their proportion of total users, as recorded in the counts of users, multiplied by the total annual users at pre and post time-points. Peak time was classified as between 7am and 9am and 4pm–7pm on weekdays. Percentage changes of people with disability or long-term illness and those living in the most deprived areas were obtained from their proportion of total users, as recorded in the surveys of users, multiplied by the total annual users at pre and post time-points. Users from the most deprived areas were those with home postcodes in the most deprived UK-adjusted IMD quintile, based on LSOA rank, following Abel et al.'s methodology (Abel et al., 2016) to adjust for differences between countries within the UK.

#### 2.4.4. Meeting physical activity guidelines

The survey of users asked: "In the past week on how many days have you completed 30 min or more physical activity that was enough to raise your breathing rate? (This may include sport, exercise and brisk walking or cycling for recreation)" with response options of 0–7 (see Appendix B). The iConnect questionnaire asked how much time over the last seven days participants walked and cycled for different purposes, as well as time spent doing moderate and vigorous intensity leisure-time physical activity (Adams et al., 2014) (see Appendix C). Since the UK Government's guidelines recommend at least 150 min of physical activity of at least moderate intensity per week (Public Health England, 2016) outcomes of at least 5 days of 30 min, or at least 150 min in total, of physical activity were used as proxies for meeting the guidelines in the surveys of users and iConnect questionnaires respectively (extreme values of reported minutes of physical activity were truncated at 1260 min). Because the guidelines include the option of 75 min of vigorous activity per week, or a mixture of vigorous and moderate intensity physical activity (Department of Health and Social Care, 2011), we made an exception in the case of users who were running at the time of the route user survey. We assumed that the average intensity of their physical activity throughout the week would be higher than for other route users (Ainsworth et al., 2011), and therefore applied a threshold of at least 4 days of 30 min' activity to define the meeting of guidelines in this group.

### 2.5. Contextual factor covariates

Schemes differed in the time between completion and post monitoring and previous research has found that it can take many months for people to start using new routes (Goodman et al., 2014), therefore this needed accounting for as a potential confounder. Additional details are included in Appendix A.

### 2.6. Demographic variables

Demographic information that may influence physical activity outcomes were included as covariates: gender, age, employment status, general health, whether respondents had a disability or long-term illness, whether they had children in the household and their

**Table 2**
Features of Connect2 schemes and sample size for each dataset (Number of schemes = 84).

| Connect2 scheme | Country | New/ Upgraded route[a] | Cost (£ million) | Length (km) | Bridge /tunnel present? | Population within 0.5 mile | Counts of users | | Survey of users | | Estimated annual route users ('000s) | | Estimated benefit-cost ratio | iConnect cohort | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | n Pre | n Post | n Pre (% of count) | n Post (% of count) | n Pre | n Post | | n 1-year | n 2-year |
| Argoed bridge | Wales | New | 0.3 | 0.04 | yes | 700 | 222 | 852 | 65 (29) | 62 (7) | 15 | 35 | 17.2 | - | - |
| Ballymoney railway bridge and links | Northern Ireland | Upgrade | 1.2 | 1.91 | yes | 6,300 | 1,166 | - | 133 (11) | 140 (-) | 93 | 197 | 11.5 | - | - |
| Bath 2 tunnels greenway | England | Upgrade | 5.2 | 6.34 | yes | 33,200 | 1,326 | 4,648 | 268 (20) | 398 (9) | 114 | 264 | 3.4 | - | - |
| Bedlington network | England | Upgrade | 2.0 | 9.48 | no | 26,700 | 1,823 | 2,333 | 150 (8) | 99 (4) | 325 | 552 | 3.3 | - | - |
| Bethnal Green local link | England | Upgrade | 2.2 | 2.90 | yes | 78,100 | 2,985 | 6,628 | 258 (9) | 240 (4) | 267 | 584 | 9.0 | - | - |
| Birmingham links to New Hall Valley | England | Upgrade | 2.1 | 19.15 | no | 61,900 | - | - | 337 (-) | 743 (-) | 351 | 437 | 4.0 | - | - |
| Blandford – Stourpaine Trailway | England | New | 0.7 | 3.67 | no | 3,700 | - | 1,626 | - (-) | 358 (22) | - | 186 | 15.0 | - | - |
| Blyth network | England | Upgrade | 2.5 | 14.45 | no | 36,600 | 2,538 | 3,152 | 192 (8) | 241 (8) | 661 | 769 | 3.5 | - | - |
| Bradford links | England | Upgrade | 3.7 | 1.87 | yes | 34,800 | 2,454 | 3,237 | 87 (4) | 129 (4) | 255 | 403 | 1.4 | - | - |
| Bristol – Nailsea: 'The Festival Way' | England | Upgrade | 1.4 | 15.25 | no | 29,300 | 5,676 | 9,176 | 720 (13) | 285 (3) | 481 | 877 | 15.2 | - | - |
| Brompton-on-Swale rural links | England | New | 0.5 | 2.94 | yes | 3,900 | 294 | 161 | 56 (19) | 58 (36) | 42 | 20 | 1.0 | - | - |
| Bury greenway | England | New | 1.0 | 2.58 | yes | 18,100 | 3,112 | 6,240 | 340 (11) | 315 (5) | 265 | 324 | 9.4 | - | - |
| Cardiff - Penarth link | Wales | Upgrade | 4.9 | 4.56 | yes | 17,500 | 2,254 | 15,704 | 614 (27) | 1,099 (7) | 275 | 512 | 3.0 | 589 | 487 |
| Carlton-Le-Moorland – Bassingham link | England | New | 0.5 | 2.05 | no | 1,900 | 377 | 1,118 | 67 (18) | 102 (9) | 46 | 79 | 5.4 | - | - |
| Cheshunt: A10 crossing and links | England | Upgrade | 2.9 | 5.01 | yes | 25,100 | 139 | 2,185 | 29 (21) | 101 (5) | 32 | 259 | 0.8 | - | - |
| Chester greenway extension, links and riverside path | England | Upgrade | 1.7 | 5.86 | yes | 32,100 | 1,438 | 1,206 | 167 (12) | 122 (10) | 1,641 | 2,129 | 21.9 | - | - |
| Clydach links | Wales | Upgrade | 1.1 | 5.38 | yes | 8,300 | 164 | 1,821 | 44 (27) | 236 (13) | 60 | 105 | 3.5 | - | - |
| Conkers path in the National Forest | England | Upgrade | 1.2 | 0.55 | no | 400 | 247 | 219 | 76 (31) | 59 (27) | 20 | 11 | 0.3 | - | - |

(continued on next page)

**Table 2** (*continued*)

| Connect2 scheme | Country | New/ Upgraded route[a] | Cost (£ million) | Length (km) | Bridge /tunnel present? | Population within 0.5 mile | Counts of users | | Survey of users | | Estimated annual route users ('000s) | | Estimated benefit-cost ratio | iConnect cohort | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | n Pre | n Post | n Pre (% of count) | n Post (% of count) | n Pre | n Post | | n 1-year | n 2-year |
| Conwy – Penmaenmawr coastal path | Wales | New | 0.9 | 1.31 | yes | 600 | 155 | 413 | 49 (32) | 96 (23) | 17 | 44 | 3.2 | - | - |
| Croydon parks links | England | Upgrade | 1.9 | 2.34 | no | 31,300 | 3,041 | 17,175 | 149 (5) | 291 (2) | 331 | 1,208 | 16.1 | - | - |
| Dartford: Darent Valley Path | England | Upgrade | 1.9 | 6.40 | yes | 27,200 | 2,621 | 1,436 | 123 (5) | 122 (8) | 164 | 222 | 3.0 | - | - |
| Derry greenway | Northern Ireland | New | 15.7 | 5.80 | yes | 14,800 | 11,462 | 10,644 | 477 (4) | 347 (3) | - | - | - | - | - |
| Dewsbury greenway links | England | Upgrade | 1.2 | 2.80 | yes | 15,100 | 260 | 734 | 90 (35) | 198 (27) | 35 | 106 | 3.2 | - | - |
| Dover greenway to city centre and seafront | England | Upgrade | 0.8 | 2.84 | yes | 20,700 | 5,584 | 7906 | 256 (5) | 328 (4) | 555 | 813 | 22.3 | - | - |
| Dumfries: Connecting two railway paths | Scotland | New | 0.6 | 2.96 | yes | 12,000 | 750 | 1,278 | 161 (21) | 444 (35) | 68 | 108 | 5.8 | - | - |
| Everton Park – Mersey waterfront links | England | Upgrade | 1.2 | 3.72 | no | 24,200 | 2,270 | 1,407 | 164 (7) | 518 (37) | 287 | 235 | 0.8 | - | - |
| Falkirk canal towpath repairs | Scotland | Upgrade | 0.3 | 2.64 | no | 12,000 | 707 | 329 | 35 (5) | 81 (25) | 44 | 45 | 3.1 | - | - |
| Foryd Harbour (Rhyl): Bridge and link | Wales | New | 6.0 | 0.88 | yes | 4,400 | 6,664 | 5,273 | 369 (6) | - (-) | - | 388 | - | - | - |
| Glasgow network | Scotland | Upgrade | 3.3 | 2.50 | yes | 27,000 | 5,451 | 11,343 | 114 (2) | 146 (1) | 681 | 902 | 1.4 | - | - |
| Hamilton – Larkhal link | Scotland | Upgrade | 2.2 | 10.55 | no | 16,900 | 1,008 | 1,327 | 39 (4) | 142 (11) | 305 | 368 | 2.1 | - | - |
| Haringey traffic-free environment | England | Upgrade | 0.4 | 0.50 | no | 30,600 | 9,503 | - | 245 (3) | 149 (-) | 773 | 902 | 10.8 | - | - |
| Harrogate: The Nidderdale Greenway | England | New | 0.7 | 4.48 | yes | 5,000 | 2,879 | 9,405 | 145 (5) | 269 (3) | 166 | 561 | 44.4 | - | - |
| Hastings – Bexhill coastal path | England | Upgrade | 0.5 | 2.27 | no | 6,400 | 968 | 2,172 | 185 (19) | 382 (18) | 104 | 218 | 17.5 | - | - |
| Havering – Ingrebourne Valley links | England | Upgrade | 4.5 | 20.66 | no | 66,800 | 1,272 | 2,897 | 88 (7) | 258 (9) | 627 | 754 | 3.3 | - | - |
| Hereford links | England | Upgrade | 0.5 | 10.57 | yes | 32,600 | - | 496 | - (-) | 49 (10) | 106 | 109 | 2.6 | - | - |
| | England | Upgrade | 0.4 | 2.80 | yes | 14,000 | 518 | 715 | 78 (15) | 93 (13) | 63 | 46 | 1.0 | - | - |

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**Table 2** (*continued*)

| Connect2 scheme | Country | New/ Upgraded route[a] | Cost (£ million) | Length (km) | Bridge /tunnel present? | Population within 0.5 mile | Counts of users | | Survey of users | | Estimated annual route users ('000s) | | Estimated benefit-cost ratio | iConnect cohort | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | n Pre | n Post | n Pre (% of count) | n Post (% of count) | n Pre | n Post | | n 1-year | n 2-year |
| Huyton local greenway | | | | | | | | | | | | | | | |
| Islington local link | England | Upgrade | 1.5 | 2.67 | no | 79,500 | 5,396 | 5,664 | 219 (4) | 121 (2) | 874 | 1,070 | 8.0 | - | - |
| Kenilworth – Burton Green greenway and link to the University of Warwick | England | New | 1.2 | 9.98 | no | 16,400 | 297 | 2,115 | 96 (32) | 303 (14) | 71 | 255 | 10.9 | 734 | 602 |
| Killamarsh – Halfway Tram Terminus – Rother Valley Country Park | England | New | 2.1 | 3.78 | no | 11,300 | 738 | 1,245 | 120 (16) | 123 (10) | 139 | 179 | 5.2 | - | - |
| Kirkby local links | England | Upgrade | 0.8 | 3.01 | no | 19,600 | 2,704 | 2,482 | 237 (9) | 218 (9) | 272 | 244 | 3.4 | - | - |
| Leeds: The Wyke Way green corridor | England | Upgrade | 0.4 | 2.07 | no | 13,500 | 1,378 | 4,156 | 84 (6) | 142 (3) | 166 | 254 | 12.4 | - | - |
| Leicestershire: Watermead Park links | England | Upgrade | 1.7 | 7.78 | yes | 20,700 | 3,033 | 7,819 | 412 (14) | 175 (2) | 431 | 607 | 8.0 | - | - |
| Luton – Harpenden link | England | Upgrade | 1.0 | 8.38 | yes | 24,700 | 583 | 1,141 | 207 (36) | 216 (19) | 64 | 146 | 6.5 | - | - |
| Merthyr Tydfil local links and to the Taff trail | Wales | New | 0.6 | 6.20 | yes | 14,100 | 404 | 187 | 48 (12) | 54 (29) | 60 | 79 | 4.7 | - | - |
| Monmouth links along the River Monnow | Wales | Upgrade | 0.6 | 1.77 | yes | 7,700 | 536 | 1,906 | 175 (33) | 205 (11) | 207 | 244 | 2.2 | - | - |
| Nantwich – Crewe link | Wales | Upgrade | 1.6 | 6.34 | no | 21,600 | 742 | 2,496 | 155 (21) | 353 (14) | 110 | 169 | 4.0 | - | - |
| Newport – Caerleon link | Wales | Upgrade | 2.5 | 8.97 | yes | 41,300 | 214 | 608 | 52 (24) | 146 (24) | 153 | 405 | 7.9 | - | - |
| Newton Abbot – Kingsteignton links | England | New | 3.0 | 7.77 | yes | 19,100 | 1,741 | 2,670 | 258 (15) | 335 (13) | 298 | 379 | 3.1 | - | - |
| Newtownabbey local links | Northern Ireland | New | 1.3 | 9.35 | yes | 24,500 | 332 | - | 65 (20) | 92 (-) | 82 | 87 | 0.5 | - | - |
| Northampton local links | England | Upgrade | 2.3 | 6.62 | no | 22,900 | 1,090 | 1,981 | 168 (15) | - (-) | 137 | 217 | 2.9 | - | - |
| Northwich network | England | Upgrade | 2.5 | 4.94 | yes | 18,800 | 1,071 | 3,653 | 149 (14) | 291 (8) | 100 | 308 | 7.9 | - | - |
| | England | Upgrade | 3.0 | 9.80 | yes | 60,100 | 1,568 | 1,014 | 290 (18) | 145 (14) | 371 | 534 | 7.6 | - | - |

(*continued on next page*)

**Table 2** (*continued*)

| Connect2 scheme | Country | New/ Upgraded route[a] | Cost (£ million) | Length (km) | Bridge /tunnel present? | Population within 0.5 mile | Counts of users | | Survey of users | | Estimated annual route users ('000s) | | Estimated benefit-cost ratio | iConnect cohort | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | n Pre | n Post | n Pre (% of count) | n Post (% of count) | n Pre | n Post | | n 1-year | n 2-year |
| Norwich network and riverside routes | | | | | | | | | | | | | | | |
| Omagh riverside path | Northern Ireland | New | 0.8 | 0.46 | yes | 1,900 | 2,537 | 2,536 | 252 (10) | 241 (10) | 38 | 42 | 0.7 | - | - |
| Ottery St Mary local links | England | New | 1.0 | 1.83 | yes | 4,300 | 587 | 1,236 | 115 (20) | 138 (11) | 70 | 103 | 3.7 | - | - |
| Padiham, Burnley and villages: Greenway, linear park and links | England | New | 2.8 | 10.17 | no | 33,000 | 2,861 | 4,423 | 190 (7) | 288 (7) | 332 | 427 | 4.1 | - | - |
| Plymouth network | England | Upgrade | 2.1 | 10.86 | no | 52,200 | 5,674 | 8,266 | 126 (2) | 287 (3) | 783 | 1,231 | 9.2 | - | - |
| Port Talbot –Pontrhydyfen – Afan Forest Park | Wales | Upgrade | 0.7 | 16.70 | yes | 20,000 | 621 | 624 | 262 (42) | 139 (22) | 108 | 170 | 8.8 | - | - |
| Radstock – Midsomer Norton '5 Arches' route | England | New | 0.9 | 2.62 | no | 12,000 | 1,498 | 3,579 | 178 (12) | 347 (10) | 19 | 69 | 2.8 | - | - |
| Rochdale network and greenway | England | Upgrade | 1.5 | 20.74 | no | 75,300 | 1,474 | 1,629 | 399 (27) | 438 (27) | 246 | 291 | 3.1 | - | - |
| Royston subway | England | Upgrade | 3.6 | 2.40 | yes | 13,700 | 638 | 754 | 69 (11) | 85 (11) | 75 | 113 | 1.0 | - | - |
| Rugby links | England | New | 1.2 | 9.29 | yes | 29,600 | 2,526 | 2,244 | 124 (5) | 321 (14) | 306 | 295 | 3.3 | - | - |
| Sale – Stretford network | England | Upgrade | 0.7 | 15.05 | no | 70,700 | 895 | 10,726 | 138 (15) | 193 (2) | 188 | 799 | 31.7 | - | - |
| Scunthorpe Ridgeway and links | England | Upgrade | 4.1 | 12.40 | no | 36,000 | 2,053 | 5,762 | 262 (13) | 342 (6) | 181 | 239 | 0.7 | - | - |
| Shoreham bridge | England | Upgrade | 11.1 | 0.80 | yes | 8,800 | - | - | 75 (-) | - (-) | 757 | 880 | 3.6 | - | - |
| Shrewsbury riverside path and network | England | Upgrade | 2.3 | 5.29 | no | 19,800 | 7,642 | 5,560 | 320 (4) | 414 (7) | 940 | 558 | 1.4 | - | - |
| Sleaford – Leasingham link | England | Upgrade | 0.9 | 2.62 | yes | 8,700 | 349 | 481 | 77 (22) | 102 (21) | 341 | 594 | 3.7 | - | - |
| South Bermondsey (South East London) links | England | Upgrade | 1.1 | 8.12 | yes | 132,300 | - | 6,410 | - (-) | 299 (5) | - | 2,096 | - | - | - |
| Southampton: Itchen | England | Upgrade | 4.0 | 8.04 | no | 57,900 | 7,480 | 8,851 | 310 (4) | 341 (4) | 873 | 652 | 1.7 | 529 | 431 |

(*continued on next page*)

**Table 2** (*continued*)

| Connect2 scheme | Country | New/ Upgraded route[a] | Cost (£ million) | Length (km) | Bridge /tunnel present? | Population within 0.5 mile | Counts of users | | Survey of users | | Estimated annual route users ('000s) | | Estimated benefit-cost ratio | iConnect cohort | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | n Pre | n Post | n Pre (% of count) | n Post (% of count) | n Pre | n Post | | n 1-year | n 2-year |
| Riverside Path and links | | | | | | | | | | | | | | | |
| St Helens: access to greenspace | England | New | 0.3 | 2.33 | no | 13,100 | - | 936 | - (-) | 90 (10) | - | 92 | - | - | - |
| St Neots network | England | Upgrade | 3.5 | 16.78 | yes | 24,800 | 1,675 | 2,613 | 111 (7) | 114 (4) | 307 | 362 | 2.1 | - | - |
| Stockbridge rural link | England | New | 0.2 | 5.75 | yes | 1,300 | - | 105 | - (-) | 7 (7) | - | 38 | 11.6 | - | - |
| Stockport – Marple through Chadkirk Country Park | England | New | 1.6 | 7.06 | yes | 21,500 | 199 | 162 | 58 (29) | 54 (33) | 34 | 31 | 0.6 | - | - |
| Swindon links to industrial sites | England | New | 0.5 | 2.33 | no | 6,600 | 446 | 1,670 | 109 (24) | 105 (6) | 268 | 247 | 11.2 | - | - |
| Titanic Quarter – Belfast city centre: Comber Greenway extension | Northern Ireland | Upgrade | 0.4 | 5.15 | no | 34,700 | 2,048 | 10,900 | 127 (6) | 822 (8) | 365 | 448 | 32.5 | - | - |
| Topsham bridge | England | New | 0.6 | 0.80 | yes | 3,100 | 1,638 | 9,567 | 160 (10) | 102 (1) | 135 | 146 | 13.2 | - | - |
| Treforest: part of the Valleys Cycle Network | Wales | Upgrade | 1.4 | 4.09 | no | 13,500 | - | 338 | 197 (-) | 106 (31) | 37 | 37 | 0.6 | - | - |
| Tyne Dock safety improvements | England | Upgrade | 0.6 | 1.60 | no | 13,100 | 1,256 | 1,650 | 208 (17) | 241 (15) | 129 | 161 | 7.6 | - | - |
| Watton – Griston links | England | New | 1.1 | 6.30 | no | 9,100 | 715 | 1,543 | 170 (24) | 136 (9) | 97 | 224 | 7.5 | - | - |
| Westminster: Connection across A40 | England | Upgrade | 0.3 | 0.19 | yes | 38,700 | 2,323 | 3,240 | 144 (6) | 219 (7) | 173 | 276 | 14.6 | - | - |
| Weymouth network | England | Upgrade | 2.6 | 14.74 | no | 32,900 | 25,386 | 25,660 | 1,825 (7) | 1,788 (7) | 2,405 | 2,375 | 6.8 | - | - |
| Whitstable: Costal path and links | England | Upgrade | 0.5 | 23.26 | yes | 44,800 | 1,413 | 2,331 | 270 (19) | 172 (7) | 1,199 | 1,260 | 17.0 | - | - |
| Wicken Fen: The Lodes Way and rural links | England | New | 2.0 | 14.50 | yes | 3,400 | - | 325 | 23 (-) | 114 (35) | 6 | 41 | 1.1 | - | - |
| Worcester links and canal towpath | England | Upgrade | 4.4 | 17.10 | yes | 57,800 | 12,161 | 18,734 | 237 (2) | 304 (2) | 2,095 | 3,346 | 30.8 | - | - |
| Workington bridge | England | New | 2.5 | 0.17 | yes | 6,000 | - | 2,283 | - (-) | 285 (12) | - | 206 | - | - | - |
| **TOTAL** | | | | | | | **189,250** | **319,531** | **15641 (8)** | **20253 (6)** | **25,312,896** | **37,799,119** | | **1,853** | **1,524** |

[a] Many Connect2 routes were a combination of new and upgraded sections. The variable in this column refers to the majority of the route (for example, a new bridge was also built as part of the Cardiff - Penarth scheme)

UK-adjusted IMD deprivation quintile. The user survey analysis also included ethnicity as a covariate, although this was not used for the iConnect cohort due to low numbers of non-white respondents. Demographic variables for respondents are shown in Table 4.

### 2.7. Statistical analysis

Analyses were performed using R (R Core Team, 2019).

A Wilcoxon non-parametric test was used to identify significance in median changes and percentage changes in pedestrians, cyclists and sub-groups of users across schemes since data were positively skewed.

Multivariable binary logistic regression analysis was conducted firstly unadjusted and then with models adjusted for each outcome (walking or cycling separately, with 50% increase or doubling in users; meeting guideline levels of physical activity): scheme level analysis models were adjusted for each independent contextual/scheme characteristic variable, and then additionally for the time from completion to post-monitoring; physical activity models were adjusted for demographic variables, and for iConnect analyses also adjusted for baseline physical activity and scheme.

Sensitivity analysis was conducted for 50% increase and doubling in number of users with disability/long-term illness and from the most deprived quintile, because these used data from the surveys of users and some schemes had low numbers of respondents for these sub-groups. Where zero sub-group users were recorded these were reassigned as one, and where the number of survey respondents differed by less than four (equivalent of one sub-group user per monitoring day) then the post-monitoring survey value was reassigned the same value as for baseline. Sensitivity analysis was also conducted for meeting guideline levels of physical activity for runners using five days of 30 min physical activity in the previous week, rather than four, since intensity of each bout of activity was unknown.

#### 2.7.1. Missing data

The surveys of users did not distinguish between zero children in the household and missing data, therefore both were treated as indicating zero children in the household. Where home postcodes were missing for user survey responses, which were used to determine UK-adjusted IMD quintiles, participants were assigned the local government IMD quintile of the scheme they were using since the majority of route users were local (77% of user survey respondents reported travelling 10 km or less to reach the route). Where demographic information was missing at baseline for iConnect but available at follow-up, the value from one-year follow-up was used, or if not available, from two-year follow up (age was adjusted down accordingly). Missing recreational physical activity values in the iConnect data were reassigned as zero where responses for transport physical activity had been completed as zero (this applied to 18 cases at baseline; 5 at one-year follow-up and 14 at two-year follow-up).

## 3. Results

### 3.1. Descriptive findings

#### 3.1.1. Scheme level use and benefit-cost ratio

The median increases in cyclists and pedestrians on the 77 Connect2 schemes with pre and post data were 51.8% and 38% respectively ($p < 0.001$). Doubling of cyclists and pedestrians occurred in 22 and 17 schemes respectively, with at least a 50% increase in 39 and 32 schemes respectively. Table D.1 and Table D.2 in Appendix D show overall change and estimated annual users for each scheme.

Table 2 includes each scheme's estimated BCR. The median BCR was 3.7 (IQR 6.6), a comparatively high value as defined by the UK's Department for Transport (Department for Transport, 2015).

#### 3.1.2. Scheme level route users

As shown in Table 3, demographic characteristics of users in the pre and post user surveys were similar overall. However, the proportion of cyclists significantly increased after scheme construction. This was found in both the manual count and survey of users. This was mostly due to increases in working-age men and women cyclists, with larger increases among men and experienced, regular cyclists, although there were also significant increases in new cyclists and those starting to cycle again, and borderline significant increases in occasional cyclists. Overall, most route users were pedestrians, white, without disability/long-term illness, travelling off-peak for recreational purposes. They were most commonly working-age men, and not from the least deprived areas.

The counts of users found increases in women and older adults in 36 schemes (52%), in peak time users in 42 schemes (61%) and in women cyclists in 47 schemes (68%). The survey of users found increases in people with disability/long-term illness in 44 schemes (62%) and users from the most deprived areas in 31 schemes (43%).

#### 3.1.3. Participant descriptive statistics

As seen in Table 4, respondents differed in demographic characteristics between datasets – the user survey respondents were most commonly male, working-age, employed full time, white, in good health, from more deprived areas and without children. The iConnect cohort were most commonly female, older, white, in good health, from the least deprived areas and without children. Users of the new routes were most commonly employed full time, whereas non-users were most commonly retired.

Just over half of the cross-sectional survey sample reported meeting guideline physical activity levels (pre 52.6%; post 53.2%). Higher proportions of the iConnect cohort reported meeting the guidelines: 66.1% of non-users and 86.8% of route users at one-year follow-up; 63.9% of non-users and 83.6% of users at two-year follow-up. The percentage of respondents in the iConnect cohort who

**Table 3**
Change in types of users across schemes using counts of users (Number of schemes = 69) and user survey (Number of schemes = 73).

| Type of user | | Pre | | | | Post | | | | Change pre-post | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total n | % | Median n | IQR | Total n | % | Median n | IQR | Median % | IQR % | p-value |
| COUNTS OF USERS (69 schemes) | | | | | | | | | | | | |
| Mode | Pedestrians | 123,448 | 77.1 | 947 | 1802 | 201,427 | 69.2 | 1413 | 2947 | −3.1 | 13 | 0.116 |
| | Cyclists | 29,589 | 18.5 | 260 | 324 | 76,899 | 26.4 | 498 | 913 | **3.5** | **12** | **0.048** |
| | Wheelchair users | 658 | 0.4 | 4 | 9 | 1124 | 0.4 | 7 | 12 | 0.1 | 0 | 0.878 |
| | Horse riders | 131 | 0.1 | 0 | 2 | 257 | 0.1 | 1 | 4 | 0.0 | 0 | 0.377 |
| | Runners | 6297 | 3.9 | 37 | 56 | 11,388 | 3.9 | 63 | 111 | 0.3 | 3 | 0.346 |
| Age group and gender | Children | 31,121 | 19.4 | 250 | 447 | 51,097 | 17.6 | 476 | 783 | −1.2 | 12 | 0.483 |
| | Working-age men | 64,393 | 40.2 | 539 | 766 | 124,331 | 42.7 | 993 | 1646 | 1.5 | 9 | 0.164 |
| | Working-age women | 47,789 | 29.8 | 393 | 582 | 86,747 | 29.8 | 602 | 1521 | 0.1 | 5 | 0.891 |
| | Older men | 9944 | 6.2 | 73 | 106 | 17,159 | 5.9 | 154 | 222 | 0.2 | 4 | 0.743 |
| | Older women | 6876 | 4.3 | 51 | 73 | 11,761 | 4.0 | 94 | 164 | 0.3 | 3 | 0.729 |
| | All women[a] | 54,665 | 34.1 | 458 | 654 | 98,508 | 33.8 | 736 | 1611 | 0.3 | 6 | 0.946 |
| | All older people[a] | 16,820 | 10.5 | 120 | 175 | 28,920 | 9.9 | 249 | 403 | 0.1 | 6 | 0.604 |
| Time of use | Peak[a] | 34,387 | 21.5 | 224 | 469 | 58,799 | 20.2 | 525 | 727 | 1.3 | 6 | 0.498 |
| | Off-peak | 125,736 | 78.5 | 1145 | 1484 | 232,296 | 79.8 | 1839 | 3444 | 3.5 | 8 | 0.498 |
| Type of cyclist | Child cyclists | 6844 | 4.3 | 60 | 101 | 13,802 | 4.7 | 123 | 509 | 0.1 | 4 | 0.920 |
| | Working-age men cyclists | 15,557 | 9.7 | 120 | 211 | 43,114 | 14.8 | 275 | 509 | **3.0** | **7** | **0.019** |
| | Working-age women cyclists | 5157 | 3.2 | 34 | 53 | 15,088 | 5.2 | 80 | 209 | **1.1** | **3** | **0.040** |
| | Older men cyclists | 1483 | 0.9 | 9 | 17 | 3526 | 1.2 | 19 | 45 | 0.2 | 1 | 0.269 |
| | Older women cyclists | 548 | 0.3 | 2 | 7 | 1369 | 0.5 | 6 | 19 | 0.1 | 0 | 0.172 |
| | All women cyclists[a] | 5705 | 3.6 | 37 | 56 | 16,457 | 5.7 | 85 | 229 | **0.9** | **3** | **0.021** |
| Counts of users TOTAL | | 160,123 | – | 1413 | 1951 | 291,095 | – | 2331 | 4428 | – | – | – |
| **SURVEYS OF USERS (73 schemes[c])** | | | | | | | | | | | | |
| Age | 16–24 | 1158 | 8.0 | 10 | 16 | 1540 | 8.2 | 15 | 18 | 0.1 | 5.7 | 0.827 |
| | 25–34 | 2149 | 14.9 | 20 | 23 | 2756 | 14.7 | 29 | 35 | 0.0 | 7.4 | 0.759 |
| | 35–44 | 2876 | 20.0 | 28 | 30 | 3762 | 20.1 | 38 | 36 | −0.8 | 7.3 | 0.787 |
| | 45–54 | 3091 | 21.5 | 30 | 30 | 4060 | 21.7 | 38 | 47 | 0.0 | 8.2 | 0.491 |
| | 55–64 | 2547 | 17.7 | 24 | 38 | 3394 | 18.1 | 31 | 40 | 0.4 | 8.5 | 0.264 |
| | 65+[a] | 1968 | 13.7 | 18 | 24 | 2838 | 15.2 | 26 | 36 | 1.3 | 7.5 | 0.329 |
| Gender | Female[a] | 5948 | 41.3 | 64 | 63 | 7641 | 40.8 | 70 | 91 | 1.2 | 12.5 | 0.352 |
| | Male | 8305 | 57.7 | 84 | 93 | 11,064 | 59.1 | 110 | 104 | −0.2 | 11.92 | 0.172 |
| Mode | Pedestrian | 11,063 | 76.8 | 114 | 127 | 13,288 | 71.0 | 127 | 151 | **−5.6** | **15.4** | **0.002** |
| | Cyclist | 2858 | 19.8 | 19 | 31 | 4799 | 25.6 | 40 | 68 | **5.9** | **14.8** | **0.002** |
| | Runner | 376 | 2.6 | 3 | 5 | 452 | 2.4 | 3 | 6 | −0.1 | 2.4 | 0.863 |
| | Wheelchair | 67 | 0.5 | 0 | 1 | 104 | 0.6 | 1 | 2 | ***0.0*** | ***0.46*** | ***0.052*** |
| | Roller skating | 8 | 0.1 | 0 | 0 | 12 | 0.1 | 0 | 0 | 0.0 | 0.0 | 0.412 |
| | Horse riding | 6 | 0.04 | 0 | 0 | 17 | 0.09 | 0 | 0 | 0.0 | 0.0 | 0.130 |
| Type of cyclist[d] | Women cyclists[a] | 754 | 5.2 | 4 | 9 | 1155 | 6.2 | 10 | 16 | **1.4** | **4.0** | **0.030** |
| | New to cycling | 48 | 0.3 | 0 | 1 | 73 | 0.4 | 0 | 2 | **0.0** | **0.4** | **0.034** |
| | Starting to cycle again | 171 | 1.2 | 1 | 3 | 296 | 1.6 | 2 | 4 | **0.02** | **1.8** | **0.018** |

(*continued on next page*)

**Table 3** (*continued*)

| Type of user | | Pre | | | | Post | | | | Change pre-post | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total n | % | Median n | IQR | Total n | % | Median n | IQR | Median % | IQR % | p-value |
| | Occasional cyclist | 225 | 1.6 | 1 | 4 | 388 | 2.1 | 2 | 5 | ***0.3*** | ***2.1*** | ***0.052*** |
| | Experienced, occasional cyclist | 536 | 3.7 | 4 | 6 | 895 | 4.8 | 7 | 11 | 0.7 | 3.6 | 0.142 |
| | Experienced, regular cyclist | 1581 | 11.0 | 10 | 19 | 2861 | 15.3 | 23 | 37 | **4.3** | **10.0** | **0.001** |
| Journey purpose on route | Commuting | 1892 | 13.1 | 14 | 25 | 2679 | 14.3 | 21 | 45 | 0.8 | 7.9 | 0.508 |
| | Recreation | 7757 | 53.9 | 73 | 76 | 10,042 | 53.6 | 99 | 95 | 1.9 | 17.8 | 0.763 |
| | Shopping | 1767 | 12.3 | 16 | 26 | 2267 | 12.1 | 17 | 41 | −0.8 | 5.1 | 0.851 |
| | Visit friends/family | 630 | 4.4 | 6 | 9 | 939 | 5.0 | 10 | 15 | 0.2 | 4.1 | 0.538 |
| | Social/entertainment | 819 | 5.7 | 8 | 12 | 988 | 5.6 | 7 | 15 | −0.3 | 4.4 | 0.163 |
| | Other[b] | 1451 | 10.1 | 13 | 19 | 1781 | 9.5 | 16 | 22 | −0.04 | 6.0 | 0.784 |
| Ethnicity | White | 12,091 | 84.0 | 138.5 | 123.75 | 17,497 | 93.5 | 170 | 189.5 | 0.04 | 3.5 | 0.930 |
| | Non-white | 507 | 3.5 | 2 | 5.5 | 729 | 3.9 | 2 | 5.25 | 0.0 | 2.0 | 0.672 |
| Disabled/long term illness | Yes[a] | 1807 | 13.4 | 16 | 20.5 | 2549 | 14.4 | 25 | 31.5 | 1.4 | 8.7 | 0.104 |
| | No | 11,708 | 86.6 | 125 | 137.5 | 15,121 | 85.6 | 168 | 159 | −1.1 | 9.2 | 0.364 |
| UK-adjusted IMD quintile (1 = most deprived) | 1[a] | 3196 | 22.2 | 14 | 61 | 4121 | 22.0 | 22 | 70 | −0.01 | 5.6 | 0.703 |
| | 2 | 3328 | 23.1 | 24 | 44 | 4132 | 22.1 | 33 | 51 | −0.2 | 9.2 | 0.956 |
| | 3 | 2803 | 19.5 | 24 | 42 | 3756 | 20.1 | 35 | 51 | 1.1 | 7.6 | 0.654 |
| | 4 | 2859 | 19.9 | 22 | 34 | 3807 | 20.3 | 34 | 52 | −1.4 | 7.1 | 0.669 |
| | 5 | 2216 | 15.4 | 12 | 43 | 2903 | 15.5 | 23 | 41 | 0.1 | 3.7 | 0.731 |
| User survey TOTAL | | 14,402 | – | 149 | 163 | 18,719 | – | 198 | 192 | – | – | – |

Total percentages may not add to 100 due to rounding and missing values.

[a] Sub-group of interest (peak time defined as 7am–9am and 4pm–7pm on weekdays; older people classified subjectively by surveyors).

[b] 'Other' includes in course of work, education, personal business, holiday base, escort to school, other escort, and other.

[c] 71 schemes were used in analyses of users from the most deprived quintile and those with a disability/long-term illness due to missing data.

[d] Type of cyclist was selected by each participant (excluding the option 'women cyclist').

**Table 4**
Comparison of participant characteristics in cross-sectional survey of users and iConnect cohort at baseline.

| Variable | Survey of users | | iConnect | | | |
|---|---|---|---|---|---|---|
| | | | 1-year follow-up | | 2-year follow-up | |
| | Pre (n = 13,343) (%) | Post (n = 19,544) (%) | Non-users of route (n = 1322) (%) | Users of route (n = 531) (%) | Non-users of route (n = 945) (%) | Users of route (n = 579) (%) |
| | n (%) | n (%) | n (%) | n (%) | n (%) | n (%) |
| **Sex** | | | | | | |
| Male | 7696 (57.7%) | 11,479 (58.7%) | 591 (44.7%) | 256 (48.2%) | 405 (42.9%) | 268 (46.3%) |
| Female | 5647 (42.3%) | 8065 (41.3%) | 731 (55.3%) | 275 (51.8%) | 540 (57.1%) | 311 (53.7%) |
| **Age** | | | | | | |
| 16–24 | 1132 (8.5%) | 1645 (8.4%) | 63 (4.8%) | 9 (1.7%) | 33 (3.5%) | 7 (1.2%) |
| 25–34 | 2054 (15.4%) | 2984 (15.3%) | 113 (8.5%) | 72 (13.6%) | 63 (6.7%) | 56 (9.7%) |
| 35–44 | 2754 (20.6%) | 4017 (20.6%) | 135 (10.2%) | 82 (15.4%) | 86 (9.1%) | 78 (13.5%) |
| 45–54 | 3003 (22.5%) | 4389 (22.5%) | 209 (15.8%) | 117 (22%) | 157 (16.6%) | 130 (22.5%) |
| 55–64 | 2487 (18.6%) | 3559 (18.2%) | 334 (25.3%) | 127 (23.9%) | 135 (14.3%) | 160 (27.6%) |
| 65+ | 1913 (14.3%) | 2950 (15.1%) | 468 (35.4%) | 124 (23.4%) | 371 (39.3%) | 148 (25.6%) |
| **Employment** | | | | | | |
| Employed full time | 6321 (47.4%) | 9973 (51%) | 436 (33%) | 229 (43.1%) | 276 (29.2%) | 235 (40.6%) |
| Employed part time | 1966 (14.7%) | 2682 (13.7%) | 197 (14.9%) | 85 (16%) | 143 (15.1%) | 96 (16.6%) |
| Retired | 2790 (20.9%) | 4083 (20.9%) | 521 (39.4%) | 169 (31.8%) | 398 (42.1%) | 202 (34.9%) |
| Other | 2266 (17%) | 2806 (14.4%) | 168 (12.7%) | 48 (9%) | 128 (13.5%) | 46 (7.9%) |
| **Ethnicity** | | | | | | |
| White | 12,840 (96.2%) | 18,712 (95.7%) | 1256 (95%) | 467 (87.9%) | 903 (95.6%) | 558 (96.4%) |
| Non-white | 503 (3.8%) | 832 (4.3%) | 56 (4.2%) | 15 (2.8%) | 39 (4.1%) | 19 (3.3%) |
| **General health in last 4 weeks** | | | | | | |
| Excellent | 3507 (26.3%) | 6020 (30.8%) | 213 (16.1%) | 182 (34.3%) | 289 (30.6%) | 154 (26.6%) |
| Good | 8680 (65.1%) | 11,866 (60.7%) | 640 (48.4%) | 316 (59.5%) | 709 (75%) | 307 (53%) |
| Fair | 913 (6.8%) | 1281 (6.6%) | 193 (14.6%) | 70 (13.2%) | 272 (28.8%) | 64 (11.1%) |
| Poor | 243 (1.8%) | 377 (1.9%) | 52 (3.9%) | 11 (2.1%) | 52 (5.5%) | 6 (1%) |
| **Deprivation quintile** | | | | | | |
| IMD 1 (= most deprived) | 3471 (26%) | 4700 (24%) | 125 (9.5%) | 24 (4.5%) | 97 (10.3%) | 23 (4%) |
| IMD 2 | 3026 (22.7%) | 4261 (21.8%) | 190 (14.4%) | 55 (10.4%) | 131 (13.9%) | 59 (10.2%) |
| IMD 3 | 2622 (19.7%) | 3834 (19.6%) | 191 (14.4%) | 90 (16.9%) | 130 (13.8%) | 90 (15.5%) |
| IMD 4 | 2309 (17.3%) | 3793 (19.4%) | 342 (25.9%) | 162 (30.5%) | 238 (25.2%) | 175 (30.2%) |
| IMD 5 | 1915 (14.4%) | 2956 (15.1%) | 474 (35.9%) | 200 (37.7%) | 349 (36.9%) | 232 (40.1%) |
| **Long-term illness or disability** | | | | | | |
| Yes | 3745 (28.1%) | 5582 (28.6%) | 377 (28.5%) | 85 (16%) | 294 (31.1%) | 105 (18.1%) |
| No | 9598 (71.9%) | 13,962 (71.4%) | 945 (71.5%) | 446 (84%) | 651 (68.9%) | 474 (81.9%) |
| **Children in household** | | | | | | |
| Yes | 3772 (28.1%) | 5593 (28.6%) | 162 (12.3%) | 97 (18.3%) | 103 (10.9%) | 97 (16.8%) |
| No (inc. missing data for survey of users) | 9633 (71.9%) | 13,968 (71.4%) | 1160 (87.7%) | 434 (81.7%) | 842 (89.1%) | 482 (83.2%) |
| **iConnect scheme** | | | | | | |
| Cardiff | 0 (0%) | 1049 (5.4%) | 313 (23.7%) | 277 (52.2%) | 231 (24.4%) | 258 (44.6%) |
| Southampton | 306 (2.3%) | 335 (1.7%) | 441 (33.4%) | 88 (16.6%) | 333 (35.2%) | 99 (17.1%) |
| Kenilworth | 88 (0.7%) | 303 (1.6%) | 568 (43%) | 166 (31.3%) | 381 (40.3%) | 222 (38.3%) |

reported using the routes increased between one-year and two-year follow-up: from 52% to 53% at Cardiff; from 17% to 23% at Southampton; and from 23% to 37% at Kenilworth.

The percentage of survey respondents reporting that their decision to use the routes was influenced by an aim of achieving exercise rose from 55% at baseline to 61% at post-monitoring. 67% of users of the routes in the post survey reported that they thought that the routes increased their physical activity (See Table D.3 and Table D.4 in Appendix D for further details about reasons for using the routes and other modes used to access them.).

### *3.2. Use and benefit-cost ratio of new walking and cycling infrastructure by local contextual factors and scheme characteristics*

Results for maximally adjusted models, shown in Fig. 1 (see Table D.5 in Appendix D for full data table), indicated that higher relative increases in cyclists and pedestrians were associated with lower baseline levels of users. The odds of observing at least a 50% increase in cyclists were reduced by nearly a quarter for each additional 10,000 annual cyclists at baseline (OR = 0.79, 95% CI = 0.63,0.92), and the odds of observing a doubling in cyclists were halved (OR = 0.52, 95% CI = 0.31, 0.77). The odds of observing at least 50% increase in pedestrians were reduced by more than a tenth for each additional 100,000 annual users at baseline (OR = 0.86, 95% CI = 0.68,1.01) and the odds of observing a doubling in pedestrians were reduced by more than three-fifths (OR = 0.39, 95% CI = 0.14, 0.78).

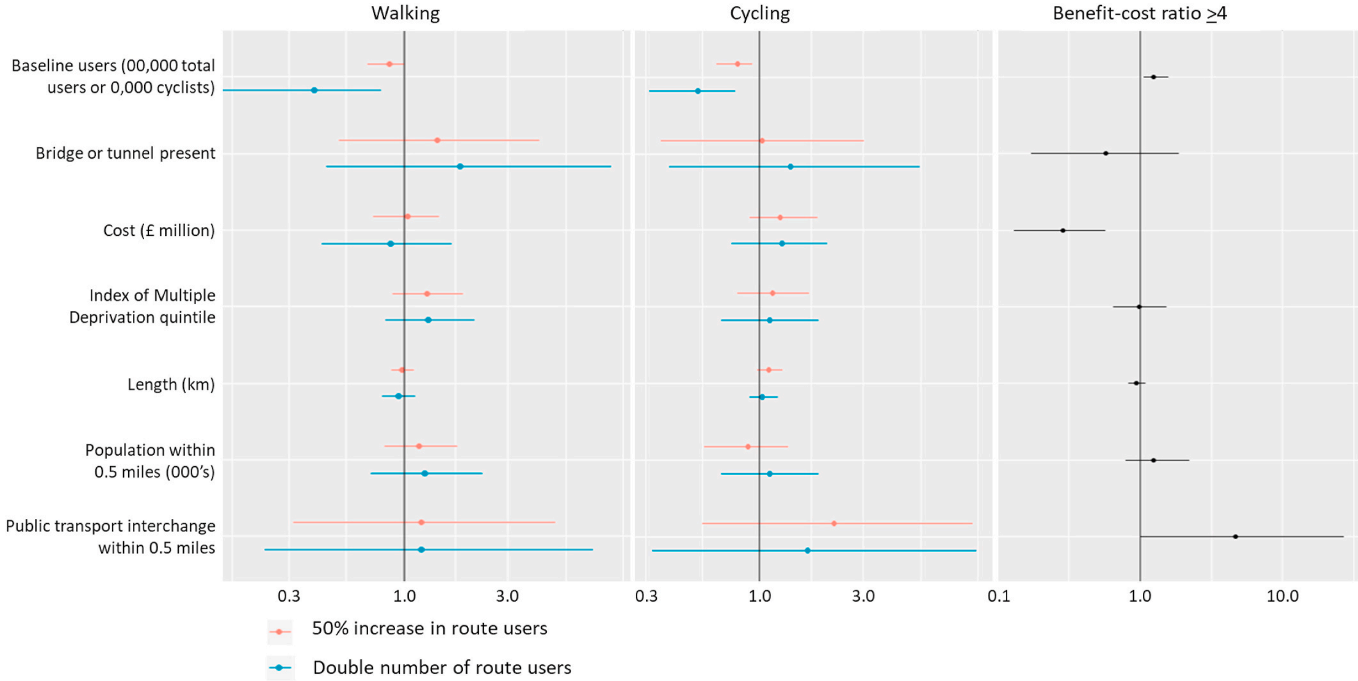


**Fig. 1.** Multivariable binary logistic regression analysis: ORs and 95% CIs for context/scheme characteristics and either at least a 50% increase or a doubling in the number of route users, and BCR across schemes, maximally adjusted for each independent contextual/scheme characteristic variable (baseline users, bridge or tunnel present, cost, index of multiple deprivation quintile, length, population within 0.5 miles, public transport interchange with 0.5 miles) and time from completion to post-monitoring (Total annual scheme users, Number of schemes = 77).

An estimated BCR of at least 4 was associated with higher baseline levels of users (per additional 100,000 annual users at baseline: OR = 1.24, 95% CI = 1.05, 1.57), lower cost schemes (per additional £1 million scheme cost: OR = 0.29, 95% CI = 0.13, 0.57) and the presence of a public transport interchange within 0.5 mile (OR = 4.64, 95% CI = 1.00, 26.62), although 95% confidence intervals were wide and the association was not significant in the unadjusted model. No other clear significant relationships were found.

### 3.3. Users of new walking and cycling infrastructure by local contextual factors and scheme characteristics

The maximally adjusted models, shown in Fig. 2 (full data in Table D.6 and sensitivity analysis results in Table D.7 of Appendix D), indicated that higher relative increases in sub-groups were associated with lower baseline levels of users, similar to that found for overall use.

High relative increases of users from the most deprived LSOAs were associated with high population levels within 0.5 miles (odds of observing at least 50% increase almost doubled for each additional 1000 population: OR = 1.93, 95% CI = 1.18, 3.67; odds of observing a doubling increased by more than half: OR = 1.54, 95% CI = 1.01, 2.52), and a bridge or tunnel present (at least 50% increase: OR = 3.51, 95% CI = 1.12, 12.16), although 95% confidence intervals were wide. There were lower odds of doubling women cyclists with a bridge or tunnel present, also with wide 95% confidence intervals (OR = 0.19, 95% CI = 0.05, 0.64).

Doubling of users of the route with a disability or long-term illness and women users were associated with less deprived IMD local government quintiles (doubling women: OR = 1.87, 95% CI = 1.14, 3.32; doubling disabled/long-term illness: OR = 1.56, 95% CI = 1.03, 2.46).

Doubling of peak time users was associated with a public transport interchange present within 0.5 miles (OR = 14.12, 95% CI = 1.54, 386.86), although the 95% confidence intervals were wide. No other clear significant relationships were found.

### 3.4. Use and meeting physical activity guidelines

As seen in Table 5, walking and cycling on the Connect2 routes were associated with meeting physical activity guidelines. In the survey of users this was found for regular route users, compared to irregular users (pre: OR = 1.80, 95% CI = 1.67, 1.94; post: OR = 1.93, 95% CI = 1.81, 2.05). Non-commuting transport users were less likely to meet the physical activity guidelines, compared to recreational users (pre: OR = 0.66, 95% CI = 0.61, 0.71; post: OR = 0.77, 95% CI = 0.72, 0.83) and runners were more likely than pedestrians to meet the guidelines (pre: OR = 1.50, 95% CI = 1.19, 1.90; post: OR = 1.51, 95% CI = 1.24, 1.84). There were no significant differences between pedestrians and cyclists, or recreational and commuting users, on the new routes.

The iConnect cohort analysis found that route users were more likely to meet the physical activity guidelines compared to non-users (at one-year follow-up: users at one-year only OR = 2.07, 95% CI = 1.37, 3.21 and users at one-year and two-year OR = 3.02, 95% CI = 2.02, 4.62; at two-year follow-up: users at two-year only OR = 2.00, 95% CI = 1.37, 2.96 and users at one-year and two-year OR = 1.66, 95% CI = 1.14, 2.45). As in the survey of users, non-commuting transport users were less likely to achieve the guidelines than recreational users (OR = 0.22, 95% CI = 0.06, 0.79), although 95% confidence intervals were wide. There was no significant difference at two-year follow-up. There were insufficient data to investigate this outcome for commuters only. Users for both recreational and transport were significantly more likely to meet the guidelines at two-year follow-up, compared to only recreational users (OR = 2.07, 95% CI = 1.18, 3.75). As in the survey of users there was no significant difference between pedestrians and cyclists in the adjusted models.

## 4. Discussion

### 4.1. Route users and context

New and upgraded routes were associated with increases in pedestrians and cyclists with large relative increases associated with low baseline levels of users. This could help to provide political support for investment in areas with existing low levels of active travel. However, places with high baseline users were associated with very high BCRs, which may create tension between investing in areas with the greatest potential for modal change (currently low levels of walking and cycling) and apparent high BCRs where currently walkable and cyclable areas may be more likely to receive investment, perpetuating inequalities in infrastructure availability. This potential tension between relative and absolute change is planned to be investigated further in future qualitative research with decision-makers. Lower cost schemes were also associated with very high BCRs, which may be as a result of relatively minor changes in infrastructure, such as on existing routes that may have improved safety or increased connectivity between key locations, attracting relatively large numbers of users at low cost.

The similarity in demographics of users found in the pre- and post-user surveys suggests that increases were roughly proportional across the whole of the population. However, the user sub-group analysis found that doubling of users who were women or had disabilities or long-term illness was associated with new routes in less deprived areas. This may be explained by people from these groups preferring to walk or cycle in places that are attractive and safe (Table D.4, Appendix D) but if used to justify investment in more affluent areas it could exacerbate health inequalities (NHS Digital, 2017).

High relative increases in route users who lived in the most deprived LSOAs were associated with high population levels within 0.5 miles of the route and with the presence of a bridge or tunnel. Creating convenient routes to access amenities on foot and by bike in high density areas, or overcoming physical barriers, is likely valued by this group (see Table D.4 in Appendix D). Furthermore they are least likely to be able to afford a car and car ownership has previously been shown to be correlated with walking and cycling (Carse

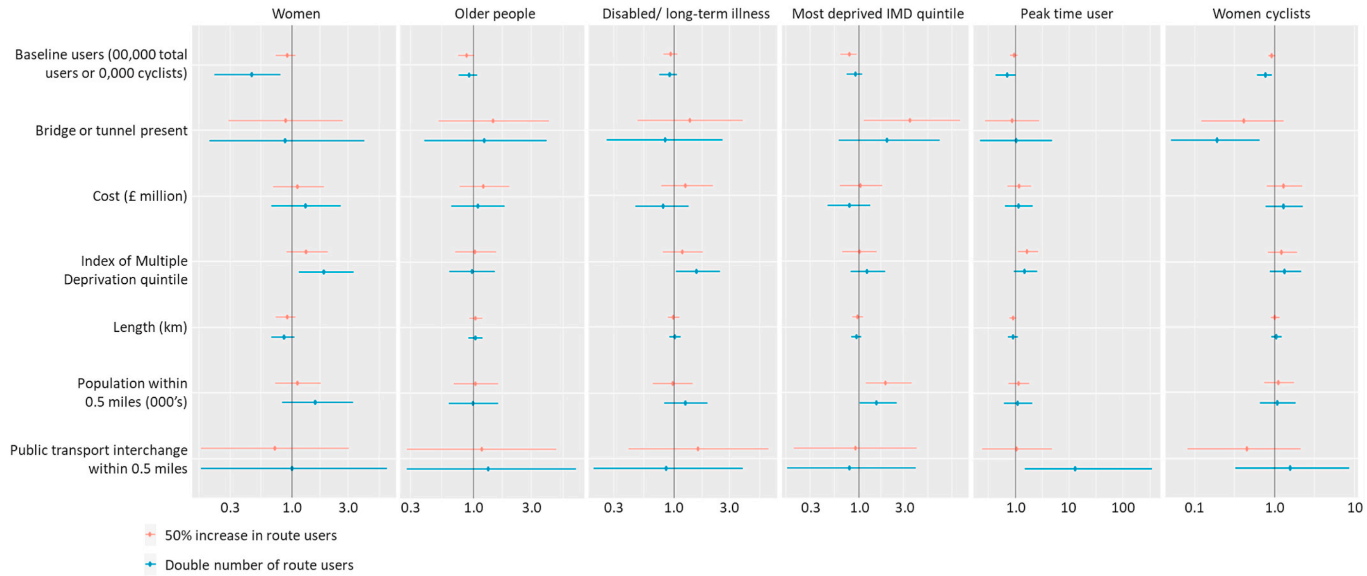


**Fig. 2.** Multivariable binary logistic regression analysis: ORs and 95% CIs for either at least a 50% increase or a doubling the number of users in each sub-group, maximally adjusted for each independent contextual/scheme characteristic variable (baseline users, bridge or tunnel present, cost, index of multiple deprivation quintile, length, population within 0.5 miles, public transport interchange with 0.5 miles) and time from completion to post-monitoring.
(Women, Older people, Peak time users, Women cyclists, Number of schemes = 69, data sets = counts of users and total annual scheme users; Disabled/long-term ill, Number of schemes = 71, Most deprived IMD quintile, Number of schemes = 73, data sets = survey of users and total annual scheme users.)

**Table 5**
Logistic regression - Survey of users: odds ratio (95% confidence interval) of meeting guideline levels of physical activity in previous week.

| Type of route user | | Survey of users: at least 5[a] days of 30 min physical activity in previous week | | | | | |
|---|---|---|---|---|---|---|---|
| | | Pre | | | | Post | |
| | | Sample (n) | % of sample achieving 5+ days | Unadjusted | Adjusted[c] | Sample (n) | % of sample achieving 5+ days |
| **User time point** | Non-user (reference) | – | – | – | – | – | – |
| | User at 1-year follow-up only | – | – | – | – | – | – |
| | User at 2-year follow-up only | – | – | – | – | – | – |
| | User at 1-year and 2-year follow-up | – | – | – | – | – | – |
| **Frequency of journey on route** | Irregularly (Weekly or less frequently) (reference) | 4562 | 43.2% | 1.00 | 1.00 | 6876 | 43.1% |
| | Regularly (Daily/2–5 times a week) | 8781 | 57.9% | **1.78 (1.66, 1.92)** | **1.80 (1.67, 1.94)** | 12,668 | 59.1% |
| **Journey purpose on route** | Recreation (reference) | 6605 | 57.1% | 1.00 | 1.00 | 10,358 | 55.6% |
| | Commuting | 1715 | 56.7% | 0.98 (0.88, 1.09) | 1.00 (0.90, 1.12) | 2751 | 56.5% |
| | Non-commuting transport[b] | 4997 | 46.2% | **0.64 (0.60, 0.69)** | **0.66 (0.61, 0.71)** | 6404 | 49.0% |
| | Recreation and transport | – | – | – | – | – | – |
| **Mode on route** | Walking (reference) | 10,441 | 52.0% | 1.00 | 1.00 | 14,046 | 53.6% |
| | Cycling | 2485 | 56.7% | **1.21 (1.11, 1.32)** | **1.12 (1.02, 1.23)** | 4839 | 53.6% |
| | Walking& cycling | – | – | – | – | – | – |
| | Running[a] | 324 | 62.7% | **1.55 (1.24, 1.95)** | **1.50 (1.19, 1.90)** | 476 | 63.9% |
| | Other | 93 | 32.3 | **0.44 (0.28, 0.67)** | **0.44 (0.28, 0.68)** | 183 | 21.9% |
| **Journey time on route (hrs)** | | 13,243 | 53.4% | **1.07 (1.04, 1.10)** | **1.05 (1.01, 1.08)** | 19,406 | 54.0% |

aAt least 4 days of 30 min of physical activity for users recorded as running.
bNon-commuting transport includes travel for shopping, visiting friends/family, social/entertainment and other purposes.
cAdjusted for demographic variables: gender (male/female), age (16–24/25-34/35–44/45-54/55–64/65+), employment (employed full time/employed part time/retired/other), ethnicity (white/non-white), general health (excellent/good/fair/poor), disability/long-term illness (yes/no), home IMD quintile, and child under 16 in the household (yes/no).
dAdjusted for baseline demographic variables: gender (male/female), age, employment (employed full time/employed part time/retired/other), general health (excellent/good/fair/poor), disability/long-term illness (yes/no), home IMD quintile, child under 16 in the household (yes/no), baseline physical activity (minutes) and scheme (Cardiff/Kenilworth/Southampton).

et al., 2013; Goodman et al., 2014; PCT Team, 2019). However, the number of women cyclists was less likely to double where a bridge or tunnel was present, an association that was not found for cyclists overall. This may be because these features reduce natural surveillance and therefore reduce perceptions of safety which tend to be highly valued by this group (Yang et al., 2019). If these features lead to employment centres they may appear less convenient for women cyclists who are more likely to conduct shorter, chain trips, such as those related to caring responsibilities (Ng and Acker, 2018). It should be noted, however, that the Connect2 schemes all involved overcoming some sort of physical barrier which is not the case for many walking and cycling routes.

High BCRs and doubling of peak time users were associated with the presence of a public transport interchange within 0.5 miles of the routes. This is consistent with other research that walking and cycling is associated with public transport use (Patterson et al., 2018) and these results could be used to justify investment in walking and cycling infrastructure near to public transport hubs because modal shift may reduce traffic congestion. Previous research from the iConnect study did not detect overall significant modal shift or carbon savings among local residents because most of their reported new use was recreational and did not replace motor vehicle trips (Brand et al., 2014; Song et al., 2017). This may reflect important differences in the ways the samples were recruited.

### *4.2. Use and physical activity*

Results showed that walking and cycling on the new routes was associated with meeting physical activity guidelines, and greater use (in terms of frequency and purpose) was associated with increased likelihood of achieving the guidelines. This builds on findings

| Survey of users: at least 5[a] days of 30 min physical activity in previous week | | iConnect: at least 150 min physical activity in previous week | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Post | | 1-year follow-up | | | | 2-year follow-up | | | |
| Unadjusted | Adjusted[c] | Sample (n) | % of sample achieving 150 min | Unadjusted | Adjusted[d] | Sample (n) | % of sample achieving 150 min PA | Unadjusted | Adjusted[d] |
| – | – | 1156 | 65.1% | 1.00 | 1.00 | 893 | 63.3% | 1.00 | 1.00 |
| – | – | 217 | 83.9% | **2.79 (1.93, 4.15)** | **2.07 (1.37, 3.21)** | 58 | 77.6% | **2.00 (1.10, 3.93)** | 1.29 (0.64, 2.74) |
| – | – | 172 | 73.3% | **1.47 (1.04, 2.12)** | 0.96 (0.64, 1.44) | 265 | 83.0% | **2.84 (2.02, 4.06)** | **2.00 (1.37, 2.96)** |
| – | – | 314 | 88.9% | **4.28 (2.99, 6.31)** | **3.02 (2.02, 4.62)** | 314 | 84.1% | **3.07 (2.22, 4.31)** | **1.66 (1.14, 2.45)** |
| 1.00 | 1.00 | – | – | – | – | – | – | – | – |
| **1.89 (1.79, 2.01)** | **1.93 (1.81, 2.05)** | – | – | – | – | – | – | – | – |
| 1.00 | 1.00 | 280 | 87.5% | 1.00 | 1.00 | 316 | 81.3% | 1.00 | 1.00 |
| 1.04 (0.95, 1.13) | 1.06 (0.97, 1.16) | 5 | 100% | *Insufficient data* | *Insufficient data* | 4 | 50% | *Insufficient data* | *Insufficient data* |
| **0.77 (0.72, 0.82)** | **0.77 (0.72, 0.83)** | 19 | 69.4% | **0.31 (0.11, 0.93)** | **0.22 (0.06, 0.79)** | 31 | 67.8% | 0.48 (0.22, 1.12) | 0.55 (0.21, 1.47) |
| – | – | 221 | 89.6% | 1.07 (0.63, 1.86) | 0.95 (0.53, 1.74) | 222 | 90.0% | **1.99 (1.20, 3.39)** | **2.07 (1.18, 3.75)** |
| 1.00 | 1.00 | 284 | 84.5% | 1.00 | 1.00 | 307 | 79.5% | 1.00 | 1.00 |
| 1.00 (0.94, 1.07) | 0.98 (0.91, 1.05) | 28 | 89.3% | 1.53 (0.51, 6.61) | 1.28 (0.38, 5.89) | 34 | 82.4% | 1.20 (0.51, 3.33) | 0.73 (0.26, 2.26) |
| – | – | 213 | 90.7% | **1.77 (1.02, 3.16)** | 1.23 (0.66, 2.37) | 232 | 90.6% | **2.14 (1.31, 3.58)** | 1.46 (0.83, 2.26) |
| **1.53 (1.27, 1.85)** | **1.51 (1.24, 1.84)** | – | – | – | – | – | – | – | – |
| **0.24 (0.17, 0.34)** | **0.26 (0.18, 0.38)** | – | – | – | – | | – | – | – |
| 1.00 (0.98, 1.03) | 1.00 (0.97, 1.02) | | – | – | – | | – | – | – |

from previous iConnect research by Goodman et al. which found that living closer to three of the Connect2 routes was associated with greater total physical activity after two years (Goodman et al., 2014). It also supports other research that demonstrates that building walking and cycling infrastructure can increase levels of physical activity to achieve public health benefits (Aldred et al., 2020; Mueller et al., 2018; Smith et al., 2019).

Whilst the baseline user survey found that people who met the guidelines were more likely to be cyclists compared to pedestrians and by those who travelled for longer, there were no significant differences between pedestrians and cyclists or by time travelled by users of the new routes. This suggests that the Connect2 schemes attracted more frequent use by a wider range of people, increasing physical activity across the population, rather than previously only attracting more active people. Runners were more likely than pedestrians to achieve the guideline levels of physical activity, however, this was not seen in the sensitivity analysis with five days of 30 min of physical activity, rather than four (see Table D.8 in Appendix D). This points to a limitation in this type of self-report data in that the intensity of activity in general was not captured in the survey, particularly since mode was not recorded for physical activity on other active days in the previous week. Self-reported physical activity is widely used but involves a trade-off between scale and cost (Branion-Calles et al., 2019; Dowd et al., 2018; Prince et al., 2008).

People using the routes for non-commuting transport purposes were less likely to achieve the physical activity guidelines compared to recreational users in the survey of users and at one-year follow-up in the iConnect cohort, whilst by two-year follow-up there was no difference between these purposes, although the confidence intervals were large. This aligns with findings from other iConnect analysis showing that it takes time for behavioural change to occur following construction of the new routes (Goodman et al., 2014). Mechanisms for behaviour change are likely to involve a combination of physical environmental and societal factors (Ogilvie et al., 2011), therefore changes in visibility of people walking or cycling on the new routes can take time to affect cultural norms and encourage physical activity across the population. This may be particularly true for non-employment destinations that were previously inaccessible or unattractive to reach by bike or on foot. Sustrans' Connect2 post-monitoring data and the iConnect cohort follow-ups were conducted over a relatively short time period and it would be advantageous to repeat measurements to understand longer-term impact.

### *4.3. Research and monitoring methods: strengths and limitations*

This study used monitoring data from 84 new walking and cycling schemes alongside research data from 3 of those schemes to understand how these different methods may be useful in understanding changes in use associated with context, and the association of use with overall physical activity. We demonstrated that both the research and monitoring methods had value - the longitudinal iConnect dataset was able to evaluate individual-level change over time, which was a major strength, whereas this was not possible in the survey of users which was unable to be adjusted for baseline levels of physical activity, nor to determine whether people continued to use the routes and the impact that may have. For example, the survey of users asked about levels of cycling experience and it was unclear whether new or occasional cyclists maintained behaviour to become experienced, regular cyclists, for which there was a significant increase. There may have been some route displacement, attracting pedestrians and cyclists from other places, but it was unclear to what extent this occurred with the questionnaire. This difficulty in understanding displacement is not uncommon (Aldred, 2019). It was not possible to identify to what extent increases in use were due to new people moving into the area, which was also a limitation of the cohort dataset. An additional limitation was that baseline measurements of some of the Connect2 schemes were conducted months or even years before construction started and it is unclear to what extent the assumption of minimal change between pre-monitoring and construction is valid.

Whilst cohort studies like iConnect have advantages they are rarely conducted. They also have limitations, therefore understanding the value of multi-site cross-sectional evaluations is useful. A strength of Sustrans' Connect2 datasets (counts, surveys of users and total annual scheme users) was the number of locations that were included, following the same methodology, and their breadth of contexts, allowing assessment of the impact of context on use, which is rarely evaluated and not clearly understood (Adkins et al., 2017; Cavill et al., 2019; Panter et al., 2019). The much larger sample sizes than the cohort study enabled greater disaggregation of sub-groups for the evaluation of use and meeting guideline levels of physical activity. However, understanding impacts by types of user sub-group at a scheme level often resulted in large confidence intervals due to the relatively small number of schemes included in the samples. It is therefore recommended that this type of multi-scheme evaluation is conducted at a greater scale to provide more reliable results about context on user sub-groups. We note that the routes were completed between 2009 and 2013 and evaluation of more recently constructed walking and cycling infrastructure would be valuable, particularly following improved cycle infrastructure design standards (Department for Transport, 2020).

Contextual issues are important to consider in complex public health intervention research (Craig et al., 2018), however, there are relevant contextual factors that were not assessed in this analysis, for example, whether additional investment or behaviour change strategies were being done in parallel that could have influenced outcomes (Sahlqvist et al., 2015). Also, because of the multi-purpose nature of the Connect2 routes, their often extensive lengths with variety of population densities along them, and the lack of information about the quality of the surrounding environment for walking and cycling, it was challenging to understand to what extent these contextual features influenced the impact of the new routes. Smaller scale qualitative or ethnographic approaches to unpacking the complexity of contextual influences may therefore be important alongside large-scale quantitative evaluation. Further qualitative research into what contextual features are important to decision-makers of new walking and cycling routes is planned.

It appeared that the survey of users was broadly representative of route users, as measured by the manual count, however this data was captured over four days for each scheme, without adjustment for weather, as is often the case in transport assessments (Aldred, 2019). The iConnect respondents who reported using the routes appeared to be less representative of route users, more likely being older, female, from less deprived areas and without children. Although representativeness of the general population may not be necessary for cohort studies since confounders can be controlled for in regression analysis (Richiardi et al., 2013) and bias was reduced by inviting a random sample of local residents to complete the questionnaires, the low response rates of the iConnect cohort (15.6% response rate (Song et al., 2017), of which 60% had complete data for inclusion in this analysis) resulted in some sub-groups of users unable to be investigated separately, such as commuters. In contrast, the survey of users found that about 14% of people overall used the routes for commuting (29% of users were recorded as commuters on the three iConnect schemes, including 52% during peak hours). However, the cross-sectional survey of users did not investigate other purposes that people used the routes for, whilst 8% of users in the iConnect cohort reported using the routes for commuting alongside other purposes. Therefore combining findings from both datasets gives a fuller picture of the impact of this infrastructure on commuting behaviour, which may be useful for influencing non-health sectors, such as transport planning, to influence the wider environmental determinants of health (Dahlgren and Whitehead, 1991).

## 5. Conclusion

Evaluations of new walking and cycling infrastructure may involve trade-offs between scale, cost, representativeness of sample and ability to capture within-participant change. Combining pragmatic monitoring methods allowing estimations of users and benefit-cost ratios with longitudinal analysis, we demonstrated that new walking and cycling infrastructure can lead to large relative increases in pedestrians and cyclists and has the potential to increase population levels of physical activity, whilst also providing very high value for money. We were also able to understand more about the role of context in attracting people to use new and improved local networks for walking and cycling, particularly from less active groups such as older people, disabled/with long-term illness and people from the most deprived areas. This study suggests that construction of new and improved walking and cycling infrastructure at scale could improve population health and reduce health inequalities.

## Credit author statement

Anna Le Gouais: Conceptualization, Methodology, Formal analysis, Writing - Original Draft. Jenna R Panter: Conceptualization, Methodology, Writing - Review & Editing, Supervision. Andy Cope: Methodology, Investigation. Jane E Powell: Conceptualization, Writing - Review & Editing. Emma L Bird: Conceptualization, Writing - Review & Editing. James Woodcock: Conceptualization, Writing - Review & Editing. David Ogilvie: Conceptualization, Methodology, Investigation, Writing - Review & Editing. Louise Foley: Conceptualization, Methodology, Writing - Review & Editing, Supervision.

**Funding**

This paper was written on behalf of the iConnect consortium (http://www.iconnect.ac.uk; Christian Brand, Fiona Bull, Ashley Cooper, Andy Day, Nanette Mutrie, David Ogilvie, Jane E Powell, John Preston and Harry Rutter), in conjunction with Andy Cope, who is employed by Sustrans. The iConnect consortium was funded by the Engineering and Physical Sciences Research Council [grant reference EP/G00059X/1].

The work was undertaken by the Centre for Diet and Activity Research (CEDAR), a UKCRC Public Health Research Centre of Excellence. Funding from the British Heart Foundation, Cancer Research UK, Economic and Social Research Council, Medical Research Council, the National Institute for Health Research, and the Wellcome Trust, under the auspices of the UK Clinical Research Collaboration, is gratefully acknowledged.

ALG, DO and JRP were supported by the Medical Research Council [grant number MC_UU_12015/6].

LF is funded and JW is partially funded by the National Institute for Health Research (NIHR) Global Health Research Group and Network on Diet and Activity. Funding from NIHR is gratefully acknowledged (grant reference 16/137/34). The views expressed are those of the author and not necessarily those of the NHS, the NIHR or the Department of Health and Social Care.

No funder had any role in the study design; data collection, analysis, or interpretation; in the writing of the report; or in the decision to submit the article for publication.

**Ethical approval statements**

The iConnect study was approved by the University of Southampton Research Ethics Committee (reference number CEE 200809-15).

The Connect2 monitoring was not conducted for academic purposes and therefore ethical approval was not sought.

**Data sharing statement**

iConnect data: The data set used in this study is managed by the MRC Epidemiology Unit at the University of Cambridge. The access policy for sharing is based on the MRC Policy and Guidance on Sharing of Research Data from Population and Patient Studies. All data sharing must meet the terms of existing participants' consent and study ethical approvals. The authors' Data Access and Sharing Policy defines the principles and processes for accessing and sharing our data. They welcome proposals for projects and aim to make data as widely available as possible while safeguarding the privacy of our participants, protecting confidential data and maintaining the reputations of our studies and participants. All data sharing is dependent on the project being approved by the study team, a data sharing agreement being in place with the University of Cambridge and resources being available to support the request. For further information please refer to the MRC Epidemiology Unit data sharing portal at http://epi-meta.medschl.cam.ac.uk.

Connect2 data: The data set used in this study is managed by Sustrans. Please apply to monitoring@sustrans.org.uk.

**Acknowledgements**

The authors thank the iConnect study participants for their cooperation, and the iConnect study team led by Karen Ghali for managing data collection.

The authors are also grateful to all the respondents of the Sustrans Connect2 surveys. Thanks also to staff at Sustrans who planned the collection of the data, and supported collation and management of data.

**Appendix A. Supplementary data**

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2020.100968.

## References


Abel, G.A., Barclay, M.E., Payne, R.A., 2016. Adjusted indices of multiple deprivation to enable comparisons within and between constituent countries of the UK including an illustration using mortality rates. BMJ Open 6, e012750. https://doi.org/10.1136/bmjopen-2016-012750.

Adams, E.J., Goad, M., Sahlqvist, S., Bull, F.C., Cooper, A.R., Ogilvie, D., Consortium, on behalf of the iConnect, 2014. Reliability and validity of the transport and physical activity questionnaire (TPAQ) for assessing physical activity behaviour. PloS One 9, e107039. https://doi.org/10.1371/journal.pone.0107039.

Adkins, A., Makarewicz, C., Scanze, M., Ingram, M., Luhr, G., 2017. Journal of the American planning association contextualizing walkability: do relationships between built environments and walking vary by socioeconomic context? https://doi.org/10.1080/01944363.2017.1322527.

Ainsworth, B.E., Haskell, W., Herrmann, S.D., Meckes, N., Bassett, D.R., Tudor-Locke, C., J, G., Vezina, J., Whitt-Glover, M., Leon, A.S., 2011. Compendium of Physical Activities: a second update of codes and MET values. Med. Sci. Sports Exerc. 43, 1575–1581.

Aldred, R., 2019. Built environment interventions to increase active travel: a critical review and discussion. Curr. Environ. Heal. reports. https://doi.org/10.1007/s40572-019-00254-4.

Aldred, R., Woodcock, J., Goodman, A., 2020. Major investment in active travel in Outer London: impacts on travel behaviour, physical activity, and health. https://doi.org/10.31235/OSF.IO/5NY4C.

Brand, C., Goodman, A., Ogilvie, D., 2014. Evaluating the impacts of new walking and cycling infrastructure on carbon dioxide emissions from motorized travel: a controlled longitudinal study. Appl. Energy 128, 284–295. https://doi.org/10.1016/j.apenergy.2014.04.072.

Branion-Calles, M., Winters, M., Nelson, T., de Nazelle, A., Panis, L.I., Avila-Palencia, I., Anaya-Boig, E., Rojas-Rueda, D., Dons, E., Götschi, T., 2019. Impacts of study design on sample size, participation bias, and outcome measurement: a case study from bicycling research. J. Transp. Health 15. https://doi.org/10.1016/j.jth.2019.100651.

Brown, B.B., Smith, K.R., 2017. Complex active travel bout motivations: gender, place, and social context associations. J. Transp. Health 6, 335–346. https://doi.org/10.1016/j.jth.2017.01.014.

Carse, A., Goodman, A., Mackett, R.L., Panter, J., Ogilvie, D., 2013. The factors influencing car use in a cycle-friendly city: the case of Cambridge. J. Transport Geogr. 28, 67–74. https://doi.org/10.1016/j.jtrangeo.2012.10.013.

Cavill, N., Davis, A., Cope, A., Corner, D., 2019. Active Travel and Physical Activity Evidence Review. Sport England.

Craig, P., Cooper, C., Gunnell, D., Haw, S., Lawson, K., Macintyre, S., Ogilvie, D., Petticrew, M., Reeves, B., Sutton, M., Thompson, S., 2012. Using natural experiments to evaluate population health interventions: new medical research council guidance. J. Epidemiol. Community Health 66, 1182–1186. https://doi.org/10.1136/jech-2011-200375.

Craig, P., Ruggiero, E. Di, Frohlich, K.L., Mykhalovskiy, E., White, M., Campbell, R., Cummins, S., Edwards, N., Hunt, K., Kee, F., Loppie, C., Moore, L., Ogilvie, D., Petticrew, M., Poland, B., Ridde, V., Shoveller, J., Viehbeck, S., Wight, D., 2018. Taking account of context in population health intervention research: guidance for producers, users and funders of research. https://doi.org/10.3310/CIHR-NIHR-01.

Criado Perez, C., 2019. Invisible Women: Exposing Data Bias in a World Designed for Men. Chatto & Windus, London.

Dahlgren, G., Whitehead, M., 1991. Policies and Strategies to Promote Social Equity in Health.

Department for Transport, 2020. Cycle infrastructure design [WWW Document]. Note 1/20. URL Local Transp. accessed 9.14.20 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/906344/cycle-infrastructure-design-ltn-1-20.pdf.

Department for Transport, 2016. Cycling and Walking Investment Strategy.

Department for Transport, 2015. Value for Money. Framework. Moving Britain Ahead.

Department for Transport, 2013. Transport analysis guidance: WebTAG [WWW document]. https://www.gov.uk/guidance/transport-analysis-guidance-webtag.

Department for Transport, 2010. National travel survey: 2010 [WWW document]. accessed 4.14.20. https://www.gov.uk/government/statistics/national-travel-survey-2013.

Department of Health and Social Care, 2011. UK physical activity guidelines [WWW Document]. accessed 2.13.19. https://www.gov.uk/government/publications/uk-physical-activity-guidelines.

Dowd, K.P., Szeklicki, R., Minetto, M.A., Murphy, M.H., Polito, A., Ghigo, E., Van Der Ploeg, H., Ekelund, U., Maciaszek, J., Stemplewski, R., Tomczak, M., Donnelly, A.E., 2018. A systematic literature review of reviews on techniques for physical activity measurement in adults: a DEDIPAC study. Int. J. Behav. Nutr. Phys. Activ. 15 https://doi.org/10.1186/s12966-017-0636-2.

Goodman, A., Panter, J., Sharp, S.J., Ogilvie, D., 2013. Effectiveness and equity impacts of town-wide cycling initiatives in England: a longitudinal, controlled natural experimental study. Soc. Sci. Med. 97, 228–237. https://doi.org/10.1016/j.socscimed.2013.08.030.

Goodman, A., Sahlqvist, S., Ogilvie, D., 2014. New walking and cycling routes and increased physical activity: one-and 2-Year findings from the UK iConnect study. Am. J. Publ. Health 104, 38–46.

Götschi, T., de Nazelle, A., Brand, C., Gerike, R., 2017. Towards a comprehensive conceptual framework of active travel behavior: a review and synthesis of published frameworks. Curr. Environ. Heal. reports. https://doi.org/10.1007/s40572-017-0149-9.

Guthold, R., Stevens, G.A., Riley, L.M., Bull, F.C., 2018. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1·9 million participants. Lancet Glob. Heal. 6, e1077–e1086. https://doi.org/10.1016/S2214-109X(18)30357-7.

Kelly, P., Kahlmeier, S., Götschi, T., Orsini, N., Richards, J., Roberts, N., Scarborough, P., Foster, C., 2014. Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship. Int. J. Behav. Nutr. Phys. Activ. 11, 15. https://doi.org/10.1186/s12966-014-0132-x.

Le Gouais, A., Foley, L., Ogilvie, D., Guell, C., 2020. Decision-making for active living infrastructure in new communities: a qualitative study in England. J. Public Health 42, e249–e258. https://doi.org/10.1093/pubmed/fdz105.

Li, T., Wei, Shaozhong, Shi, Y., Pang, S., Qin, Q., Yin, J., Deng, Y., Chen, Q., Wei, Sheng, Nie, S., Liu, L., 2016. The dose–response effect of physical activity on cancer mortality: findings from 71 prospective cohort studies. Br. J. Sports Med. 50, 339–345. https://doi.org/10.1136/bjsports-2015-094927.

Macmillan, F., George, E.S., Feng, X., Merom, D., Bennie, A., Cook, A., Sanders, T., Dwyer, G., Pang, B., Guagliano, J.M., Kolt, G.S., Astell-Burt, T., 2018. Do natural experiments of changes in neighborhood built environment impact physical activity and diet? A systematic review. Int. J. Environ. Res. Publ. Health 15. https://doi.org/10.3390/ijerph15020217.

Marmot, M., Allen, J., Boyce, T., Goldblatt, P., Morrison, J., 2020. Health Equity in England: the Marmot Review 10 Years on.

Mueller, N., Rojas-Rueda, D., Salmon, M., Martinez, D., Ambros, A., Brand, C., de Nazelle, A., Dons, E., Gaupp-Berghausen, M., Gerike, R., Götschi, T., Iacorossi, F., Int Panis, L., Kahlmeier, S., Raser, E., Nieuwenhuijsen, M., 2018. Health impact assessment of cycling network expansions in European cities. Prev. Med. 109, 62–70. https://doi.org/10.1016/j.ypmed.2017.12.011.

Ng, W.-S., Acker, A., 2018. Understanding Urban Travel Behaviour by Gender for Efficient and Equitable Transport Policies.

NHS Digital, 2017. Health Survey for England 2016 - Physical Activity in Adults.

Norwood, P., Eberth, B., Farrar, S., Anable, J., Ludbrook, A., 2014. Active travel intervention and physical activity behaviour: an evaluation. Soc. Sci. Med. 113, 50–58. https://doi.org/10.1016/j.socscimed.2014.05.003.

Ogilvie, D., Bull, F., Cooper, A., Rutter, H., Adams, E., Brand, C., Ghali, K., Jones, T., Mutrie, N., Powell, J., Preston, J., Sahlqvist, S., 2012. Evaluating the travel, physical activity and carbon impacts of a "natural experiment" in the provision of new walking and cycling infrastructure: methods for the core module of the iConnect study. BMJ Open 2, 13. https://doi.org/10.1136/bmjopen-2011-000694.

Ogilvie, D., Bull, F., Powell, J., Cooper, A.R., Brand, C., Mutrie, N., Preston, J., Rutter, H., 2011. An applied ecological framework for evaluating infrastructure to promote walking and cycling: the iConnect study. Am. J. Publ. Health 101, 473–481. https://doi.org/10.2105/AJPH.2010.198002.

Ogilvie, D., Craig, P., Griffin, S., Macintyre, S., Wareham, N.J., 2009. A translational framework for public health research. BMC Publ. Health 9. https://doi.org/10.1186/1471-2458-9-116.

Ogilvie, David, Egan, M., Hamilton, V., Ogilvie, D., 2005. Systematic reviews of health effects of social interventions: 2. Best available evidence: how low should you go? J. Epidemiol. Community Health 59, 886–892. https://doi.org/10.1136/jech.2005.034199.

Panter, J., Guell, C., Humphreys, D., Ogilvie, D., 2019. Can changing the physical environment promote walking and cycling? A systematic review of what works and how. Heal. Place, 58. https://doi.org/10.1016/j.healthplace.2019.102161.

Panter, J., Ogilvie, D., Brand, C., Bull, F., Cooper, A., Day, A., Mutrie, N., Ogilvie, D., Powell, J., Preston, J., Rutter, H., 2017. Can environmental improvement change the population distribution of walking? J. Epidemiol. Community Health 71, 528–535. https://doi.org/10.1136/jech-2016-208417.

Patterson, R., Webb, E., Millett, C., Laverty, A.A., 2018. Physical activity accrued as part of public transport use in England. J. Public Health 41, 222–230. https://doi.org/10.1093/pubmed/fdy099.

PCT Team, 2019. Manual C. PCT Methodology: Commuting Layer.

Prince, S.A., Adamo, K.B., Hamel, M.E., Hardt, J., Gorber, S.C., Tremblay, M., 2008. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int. J. Behav. Nutr. Phys. Activ. 5 https://doi.org/10.1186/1479-5868-5-56.

Public Health England, 2016. Health matters: getting every adult active every day [WWW Document]. accessed 11.12.18. https://www.gov.uk/government/publications/health-matters-getting-every-adult-active-every-day/health-matters-getting-every-adult-active-every-day.

R Core Team, 2019. R: A Language and Environment for Statistical Computing.

Richiardi, L., Pizzi, C., Pearce, N., 2013. Commentary: representativeness is usually not necessary and often should be avoided. Int. J. Epidemiol. 1018–1022. https://doi.org/10.1093/ije/dyt103.

Sahlqvist, S., Goodman, A., Jones, T., Powell, J., Song, Y., Ogilvie, D., 2015. Mechanisms underpinning use of new walking and cycling infrastructure in different contexts: mixed-method analysis. Int. J. Behav. Nutr. Phys. Activ. 12, 15. https://doi.org/10.1186/s12966-015-0185-5.

Sahlqvist, S., Song, Y., Ogilvie, D., 2012. Is active travel associated with greater physical activity? The contribution of commuting and non-commuting active travel to total physical activity in adults ☆. Prev. Med. 55, 206–211. https://doi.org/10.1016/j.ypmed.2012.06.028.

Sattelmair, J., Pertman, J., Ding, E.L., Kohl, H.W., Haskell, W., Lee, I.M., 2011. Dose response between physical activity and risk of coronary heart disease: a meta-analysis. Circulation 124, 789–795. https://doi.org/10.1161/CIRCULATIONAHA.110.010710.

Smith, A.D., Crippa, A., Woodcock, J., Brage, S., 2016. Physical activity and incident type 2 diabetes mellitus: a systematic review and dose–response meta-analysis of prospective cohort studies. Diabetologia 59, 2527–2545. https://doi.org/10.1007/s00125-016-4079-0.

Smith, L., Panter, J., Ogilvie, D., 2019. Characteristics of the environment and physical activity in midlife: findings from UK Biobank. Prev. Med. 118, 150–158. https://doi.org/10.1016/j.ypmed.2018.10.024.

Smith, M., Hosking, J., Woodward, A., Witten, K., Macmillan, A., Field, A., Baas, P., Mackie, H., 2017. Systematic literature review of built environment effects on physical activity and active transport – an update and new findings on health equity. Int. J. Behav. Nutr. Phys. Activ. 14 https://doi.org/10.1186/s12966-017-0613-9.

Song, Y., Preston, J., Ogilvie, D., 2017. New walking and cycling infrastructure and modal shift in the UK: a quasi-experimental panel study. Transport. Res. Part A Policy Pract. 95, 320–333. https://doi.org/10.1016/j.tra.2016.11.017.

Song, Y., Preston, J.M., Brand, C., 2013. What explains active travel behaviour? Evidence from case studies in the UK. Environ. Plann. 45, 2980–2998. https://doi.org/10.1068/a4669.

Sustrans, 2013a. Methodology for the Estimation of Economic Benefits.

Warburton, D.E.R., Bredin, S.S.D., 2017. Health benefits of physical activity: a systematic review of current systematic reviews. Curr. Opin. Cardiol. 32, 541–556. https://doi.org/10.1097/HCO.0000000000000437.

World Health Organization, 2011. Health Economic Assessment Tool.

Yang, Y., Wu, X., Zhou, P., Gou, Z., Lu, Y., 2019. Towards a cycling-friendly city: an updated review of the associations between built environment and cycling behaviors (2007–2017). J. Transp. Health. https://doi.org/10.1016/j.jth.2019.100613.